PB81-168403

Assessment of Current Information on Overland Flow Treatment of Municipal Wastewater

(U.S.) Environmental Protection Agency
Washington, DC

May 80

U.S. Department of Commerce
National Technical Information Service
NTIS

BIBLIOGRAPHIC INFORMATION

PB81-168403

Assessment of Current Information on Overland Flow Treatment of Municipal Wastewater,

May 80

Daniel J. Hinrichs, Justine A. Faisst, and David A Pivetti.

PERFORMER: Environmental Protection Agency, Washington, DC.
Office of Water Program Operations.
EPA-430/9-80-002, EPA/MCD-66

This report provides a technical discussion of recent information on design and performance of the overland-flow treatment process. Overland-flow treatment of municipal wastewaters is a rapidly developing technology which is attractive as a simple and low cost solution for smaller communities. It is the land treatment approach which is suited to locations with impermeable soils that could not be used for other land treatment approaches.

KEYWORDS: *Irrigation, *Sewage treatment, *Municipalities, *Land application, *Sewage irrigation.

Available from the National Technical Information Service, Springfield, Va. 22161

PRICE CODE: PC A07/MF A01

United States
Environmental Protection
Agency

Office of Water
Program Operations (WH-547)
Washington,DC 20460

May 1980
430/9-80-002

PB81-168403

Water

Assessment Of Current Information On Overland Flow Treatment Of Municipal Wastewater

MCD-66

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

Disclaimer Statement

This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

NOTES

To order this publication, "Assessment of Current Information on Overland Flow Treatment of Municipal Wastewater" (MCD-66) from EPA, write to:

General Services Administration (8BRC)
Centralized Mailing Lists Services
Bldg. 41, Denver Federal Center
Denver, Colorado 80225

Please indicate the MCD number and title of publication.

Multiple copies may be purchased from:

National Technical Information Service
Springfield, Virginia 22151

Assessment Of Current Information On Overland Flow Treatment Of Municipal Wastewater

By
Daniel J. Hinrichs
Justine A. Faisst
David A. Pivetti
Culp/Wesner/Culp
and Edward D. Schroeder
University of California, Davis

May 1980

Project Officer
Richard E. Thomas
Office of Water Programs
U.S. Environmental Protection Agency
Washington, D.C. 20460

EPA Comment

This report provides a technical discussion of recent information on design and performance of the overland-flow treatment process. Overland-flow treatment of municipal wastewaters is a rapidly developing technology which is attractive as a simple and low cost solution for smaller communities. It is the land treatment approach which is suited to locations with impermeable soils that could not be used for other land treatment approaches.

This report is an interim publication providing needed information on a subject for which new information is being produced rapidly. The EPA design manual on land treatment technologies is being revised and the information in this report will be updated with issuance of the revised manual.

Harold P. Cahill

Harold P. Cahill, Jr.
Director
Municipal Construction Division (WH-547)

ACKNOWLEDGEMENTS

Preparation of this report was enhanced through comments and references provided by Richard Thomas. Cost information was developed by Robert Williams. Figures were prepared by Candy Erwin and Robert Livingston. Typing and editing were completed by Karen Busse and Sharon Robbins with assistance from Sue Howard, Sherry Olives, and May Bray.

Information on site visitations was provided by Dr. Curtis Harlan and Bert Bledsoe, Ada, OK; Dr. Charles Muchmore, Carbondale, IL; James Martel, Hanover, N.H.; Robert Smith, Davis, CA; Dr. A. Ray Abernathy, Clemson University, S.C.; and Charles Neeley, Paris, TX.

PREFACE

Land treatment of municipal wastewater is becoming a popular method of treatment and reclamation. One of the newest land treatment methods is overland flow. Developments in overland flow treatment understanding and design have been recent. At this time most literature is lacking in specifics of overland flow treatment. This report has been developed to fill this need for understanding of overland flow treatment.

TABLE OF CONTENTS

Subject **Pages**

ACKNOWLEDGEMENTS iii
DISCLAIMER iv
PREFACE v
ABBREVIATIONS x
CONVERSION FACTORS xi
SECTION I - INTRODUCTION 1
SECTION II - REVIEW OF EXISTING PROJECTS 4
SECTION III - PROCESS MECHANISMS 55
SECTION IV - DESIGN CONSIDERATIONS 57
SECTION V - DESIGN EXAMPLES 67
SECTION VI - STATE REGULATIONS 79
SECTION VII - CONCLUSIONS AND RECOMMENDATIONS 80
REFERENCES 81
APPENDIX A - COSTS
APPENDIX B - STATE OF MARYLAND AND DESIGN GUIDE FOR LAND TREATMENT
APPENDIX C - STATE OF MISSISSIPPI DESIGN GUIDANCE FOR LAND TREATMENT

LIST OF FIGURES

Number		Page
1	Overland flow schematic	2
2	Schematic of Davis pilot overland flow site	6
3	City of Davis, schematic of new overland flow system	9
4	Schematics of distribution systems used at Pauls Valley	15
5	Utica, Mississippi overland flow site	22
6	Cedar Lane Trailer Park oxidation pond	25
7	Overland flow slope at Cedar Lane Trailer Park	27
8	BOD_5 removal vs. hydraulic loading rate	32
9	BOD_5 removal vs. organic loading rate	33
10	BOD_5 removal vs. detention time at Carbondale	35
11	Suspended solids removal vs. detention time at Carbondale	36
12	Nitrogen removal vs. detention time at Carbondale	37
13	Phosphorus removal vs. detention time at Carbondale	38
14	Diagram of Hanover overland flow system	40
15	Average weekly runoff BOD concentration vs. soil temperature (primary section) at Hanover	43
16	Average weekly runoff NH_4 concentration vs. soil temperature for primary and secondary sections	44
17	BOD removal vs. detention time for CRREL overland flow site receiving primary effluent	46
18	Suspended solids removal vs. detention time for CRREL overland flow site receiving primary effluent	47
19	Relationship between hourly hydraulic loading and detention time at Hanover and Utica	49
20	Hydraulic loading	59
21	Hydraulic loading	60

LIST OF TABLES

Number		Page
1	Summary of discharge requirements city of Davis	5
2	Oxidation pond effluent application rates to Davis pilot overland flow system 11/7/75 to 2/7/76	5
3	Oxidation pond effluent application rates to Davis pilot overland flow system 2/27/76 to 3/28/76	5
4	Monthly average effluent suspended solids values at Davis, mg/L	7
5	Monthly Average BOD_5 values at Davis, mg/L	7
6	City of Davis system (under construction)	8
7	Hunt-Wesson site characteristics	12
8	Ada site characteristics	13
9	Mean wastewater characteristics, mg/L	14
10	Wastewater characteristics at Pauls Valley, mg/L	16
11	Average results and significant design factors from the raw system for the winter application at Pauls Valley	17
12	Average results and significant design factors from the raw system for the summer application at Pauls Valley	18
13	Average results and significant design factors from the secondary system for the winter application at Pauls Valley	19
14	Analytical results and significant design factors from the secondary system, for the summer application at Pauls Valley	20
15	Utica overland flow site characteristics	21
16	Oxidation pond effluent characteristics at Utica	23
17	Treatment results at Utica - 1976-1977	23
18	Percent nitrogen removals at Utica - 1976-1977	24
19	Percent phosphorus removal at Utica - 1976-1977	24
20	State of Illinois water quality standards	26
21	Oxidation pond effluent characteristics at Cedar Lane	26
22	Carbondale site characteristics	28
23	1976-77 loading rates of Cedar Lane Trailer Park overland flow system	29
24	Detention time as a function of position and application rate	30
25	BOD_5 removal in Carbondale overland flow system	30
26	Suspended solids removal in Carbondale overland flow system	30
27	Phosphorus removal in Carbondale overland flow system	31
28	Nitrogen removal in Carbondale overland flow system	31
29	Hanover site characteristics	39
30	Average wastewater quality applied to CRREL overland flow slopes May 30, 1977 to April 1, 1978	41
31	Average performance from CRREL overland flow slopes	42
32	Easley site characteristics	49
33	Easley, SC overland flow system performance	49
34	Campbell's Soup, Paris, Texas site characteristics	50
35	Performance summary at Campbell's Soup, Paris, Texas	51
36	Existing overland flow system descriptions and data-summer/winter	54
37	Site characteristics - design examples	67
38	Design criteria - example 1	68
39	Design example 1 - water balance 1	69
40	Design example 1 - BOD_5 removal 1	70

LIST OF TABLES (Continued)

Number		Page
41	Design example 1 - water balance 2	71
42	Design example 1 - BOD_5 removal 2	71
43	Design criteria for example 2	72
44	Example 2 - facilities sizing	73
45	Water balance - example 2	74
46	BOD_5 reduction - example 2	75
47	Design criteria - example 3	75
48	Example 3 - facilities sizing	76
49	Design example 1 - water balance	77
50	Example 3 - nitrogen removal	78
51	Capital cost estimate - design examples	78

ABBREVIATIONS

ave	average
ft-c	foot-candle
lx	lux
mg/L	milligram/liter
m^3/d	cubic meter/day
m	meter
kg	kilogram
ha	hectare
d	day
hr	hour
min	minute
wk	week
mo	month
yr	year
cm	centimeter
km	kilometer
psig	pounds/per square inch (gage)
°C	°Celsius
°F	°Fahrenheit
mgd	million gallons per day
BOD_5	biochemical oxygen demand
SS (V)	suspended solids (volatile)
SS (T)	suspended solids (total)
NH_4-N	ammonia nitrogen as nitrogen
NO_3-N	nitrate nitrogen as nitrogen
NO_2-N	nitrite nitrogen as nitrogen
PO_4-P	phosphate as phosphorus
gal	gallon

CONVERSION FACTORS

Application	From: English Units	To: SI Units	Multiply By
application rate	gallon/minute	liter/minute (L/min)	3.785
area	acre	hectare (ha)	0.4047
distance	mile	kilometer	1.609
flow	million gallon/day	cubic meter/day (m^3/d)	3,785
illumination	foot-candle	lux (lx)	10.76
length	foot	meter (m)	0.3048
hydraulic loading	inch	centimeter (cm)	2.54
organic loading	pound/acre	kilogram/hectare (kg/ha)	1.121
pressure	pounds/square inch	kilopascal (kPa)	6.895
temperature	°F	°C	(°F-32)/1.8
volume per area	gal/acre	liter/hectare (L/ha)	9.354

ASSESSMENT OF CURRENT INFORMATION ON OVERLAND FLOW TREATMENT OF MUNICIPAL WASTEWATER

SECTION I

INTRODUCTION

Since the mid-1970's land treatment has become a popular, although controversial method of wastewater treatment and disposal. The controversy has primarily resulted from the conceptual differences between land treatment and conventional mechanical treatment processes. The major differences are the deceptively simple characteristics of land treatment systems, the as yet unclear regulatory constraints, and the lack of understanding of land treatment system design. The least understood type of land treatment is overland flow.

At the present time very little information is available to design engineers on overland flow treatment other than that presented in the 1977 document Process Design Manual for Land Treatment of Municipal Wastewater[1]. At that time considerable experience and data were available on treating cannery wastes by overland flow, but little was available on municipal wastewater treatment. Since 1977 a number of full scale municipal facilities have been designed, two have begun operation and results from many research projects have become available.

Current overland flow treatment systems are of two types; those that are used to polish secondary effluent (e.g. from an oxidation pond) and those that are used for secondary (and possibly primary) treatment. In either case substantial nutrient and heavy metal removal can be accomplished in addition to the removal of organics and suspended solids.

Typical overland flow systems are shown schematically in Figure 1. An overland flow system provides wastewater treatment by applying influent at the top of a sloped terrace (2-8% slope) and allowing a film flow down the slope to a collection ditch. This terrace is constructed on impermeabile or nearly impermeable soils planted with grass. Little infiltration occurs. The treatment process is a combination physical- chemical-biological process. The planted grass provides protection from erosion as well as being an integral part of the treatment process. The process has been described as being very similar to a trickling filter treatment process.

The purpose of this report is to provide a review of the recent applications of overland flow and a design guide based on recent operating experience. Visits were made to seven systems: Davis, CA (research, industrial and completed full scale design); Carbondale, IL (research data to full scale); Hanover, NH (research); Easley, SC (full-scale operation); Ada, OK (research) Utica, MS (research); and Paris, TX (full-scale cannery). Detailed descriptions of these projects, as well as observations made during the site visits, are presented in the following section. This information, together with information from the literature, is used to develop and present recommendations on preapplication treatment, design procedures and cost estimation.

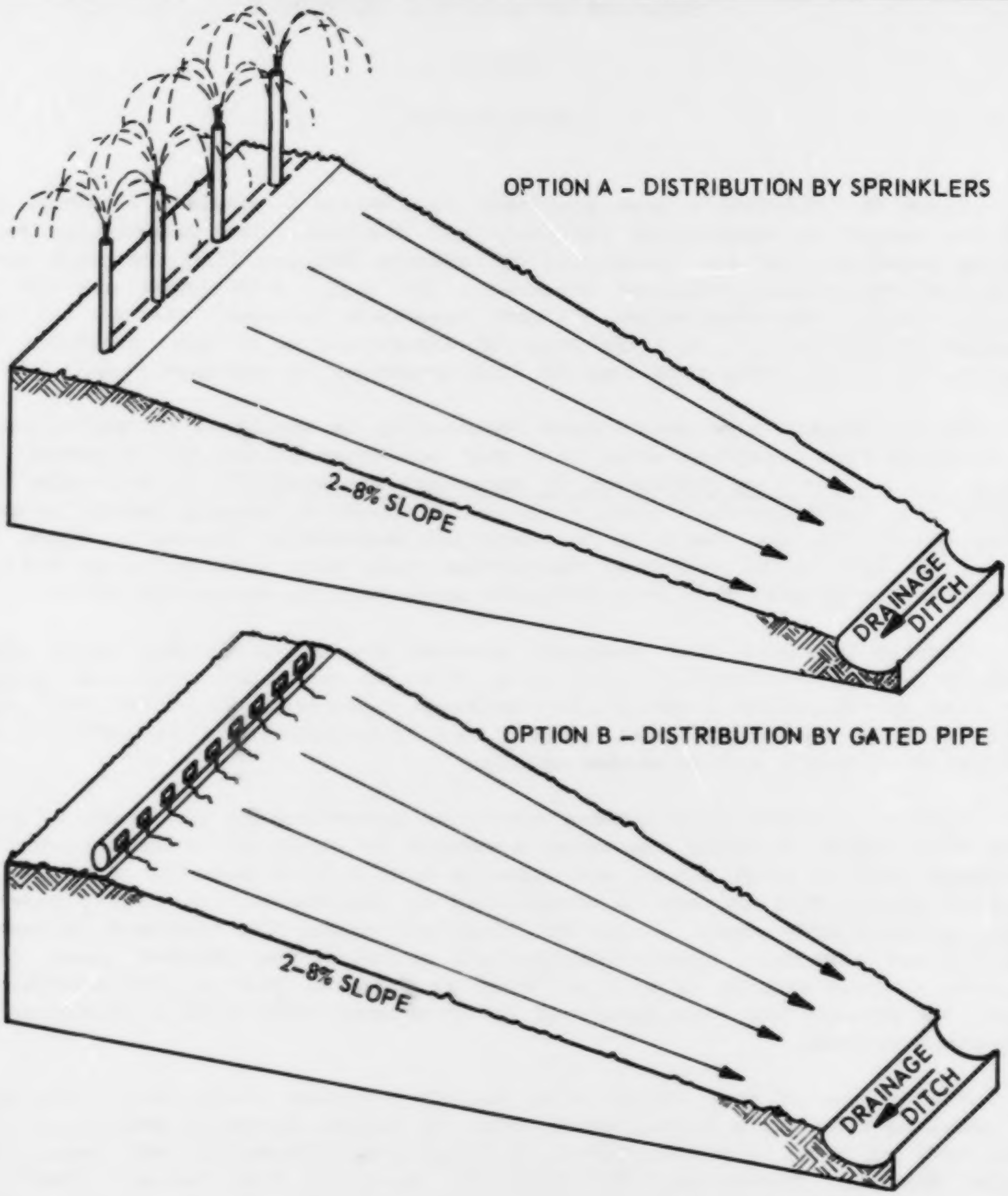

OPTION A – DISTRIBUTION BY SPRINKLERS
2-8% SLOPE
DRAINAGE
DITCH
OPTION B – DISTRIBUTION BY GATED PIPE
2-8% SLOPE
DRAINAGE
DITCH

Figure 1. Overland flow schematic.

This report has been prepared to be used independently for overland flow system design. Much of the information presented in Reference 1 will be used and supplemented or updated as necessary.

The following parameter definitions[2] are used for this report.

Hydraulic loading rate (HLR) is the volume of wastewater applied per day or per week, cm/day or cm/wk.

Application rate (AR) is the volume of wastewater applied to the slope divided by the application time period, ml/min or 1/min.

Application time period (ATP) is the length of time water is applied to the slope in a 24-hr time period, hr/d.

Application frequency (AF) refers to the sequence of application days and nonapplication days (e.g. 6 days on - 1 day off).

Organic loading rate (OLR) is the mass of organic material applied per day divided by slope of area, kg/ha-d.

Nitrogen loading rate (NLR) is the mass of nitrogen applied per day divided by the slope area, kg N/ha-d.

Smith and Schroeder[2] recommended standardization of hydraulic loading rate by noting the slope length of the rate (e.g. cm/d/30m). Similarly, application rate is standardized by expressing on a unit width basis (e.g. 1/min-m).

SECTION II

REVIEW OF EXISTING PROJECTS

Site visitations were conducted between October and December, 1979. Prior to each visit, information on the overland flow system to be visited was collected and studied. Information available on each site varied considerably. A number of the sites were research facilities. Because of their small size and constrained objectives of the research investigation, usable construction and generating cost information was lacking. A summary of the data obtained from these visits is presented at the end of this section (Table 36).

DAVIS, CA

Davis, CA is the location of three overland flow projects worthy of review: the Hunt-Wesson foods facility which provides treatment of tomato processing wastes, the research work being conducted at the University of California, Davis Campus (UCD), and the design of the City of Davis' municipal treatment system, which included pilot plant studies.

Davis, CA is a university community of approximately 38,000 persons located 20 km west of Sacramento in California's Central Valley. Hunt-Wesson, a seasonal tomato processor, operates a separate treatment and disposal system using the overland flow process. The City of Davis sewage consists entirely of residential and commercial wastewaters. Current average dry weather flow is about 13,250 m^3/d.

The climate of the Davis area is Mediterranean, with wet, mild winters and hot, dry summers. Temperatures below 0°C occur 17 days per year on the average and the frost-free growing season is 258 days. Precipitation averages 42 cm/yr with 70 percent coming in the months of December through March. Summer temperatures are usually in excess of 32° C and frequently exceed 38° C.

City of Davis

The present Davis wastewater treatment system consists of comminution, grit removal, primary sedimentation, and secondary treatment in three oxidation ponds operated in parallel followed by chlorination.

Discharge requirements of the City were set by the California Regional Water Quality Control Board and are shown in Table 1. An overland flow system was chosen to upgrade the ponds to meet these new standards.

Pilot studies were made during the period October, 1975 through March, 1976 using three, 15 x 30-m plots located at the wastewater treatment plant.

The overland flow test plots were constructed on a two percent slope on clayey soil. Each plot was flooded with digester supernatant and seeded with annual rye grass on October 1, 1975. Five spray nozzles were installed on 0.6-m risers at 3-m intervals along the upper edge of each plot.

TABLE 1. SUMMARY OF DISCHARGE REQUIREMENTS CITY OF DAVIS

Constituent	Units	30 day average	7 day average	Max
BOD_5	mg/L	30	45	90
	kg/day*	568	852	
Suspended solids	mg/L	30	45	90
	kg/day*	568	852	
pH must be greater than 6.5 and less than 8.5				

*kg/day value is the mass concentration times the flow rate. The design flow rate of the Davis Wastewater Treatment Plant is 18,925 m^3/d.

Pond effluent was pumped from the chlorination basin effluent line at a nominal pressure of 550 kPa. Separate pressure regulators and solenoid valves were used to control flow to each plot. A schematic of the system is shown in Figure 2.

Germination and growth of the annual rye grass was rapid and controlled effluent loading was begun on November 7, 1975. The grass was not cut during the 5-month study and eventually reached a height of about 30 cm. Pond effluent was applied to the plots at the rates shown in Tables 2 and 3.

TABLE 2. OXIDATION POND EFFLUENT APPLICATION RATES TO DAVIS PILOT OVERLAND FLOW SYSTEM 11/7/75 to 2/7/76

Plot	1	2	3
Application time, hr			
Morning	3	2	1
Afternoon	3	2	1
Average flow rate			
m^3/ha-hr	32.5	31.3	34.8
Daily application rate			
m^3/ha-d	195	125	69.6
cm/d	2	1.2	0.7

TABLE 3. OXIDATION POND EFFLUENT APPLICATION RATES TO DAVIS PILOT OVERLAND FLOW SYSTEM 2/27/76 to 3/28/76

Plot	1	2	3
Application time, hr			
Morning	3	4	12
Afternoon	3	4	
Average flow rate			
m^3/ha-hr	51.7	51.4	43.3
Daily application rate			
m^3/ha-d	310	412	520
cm/d	3.0	4.1	5.3

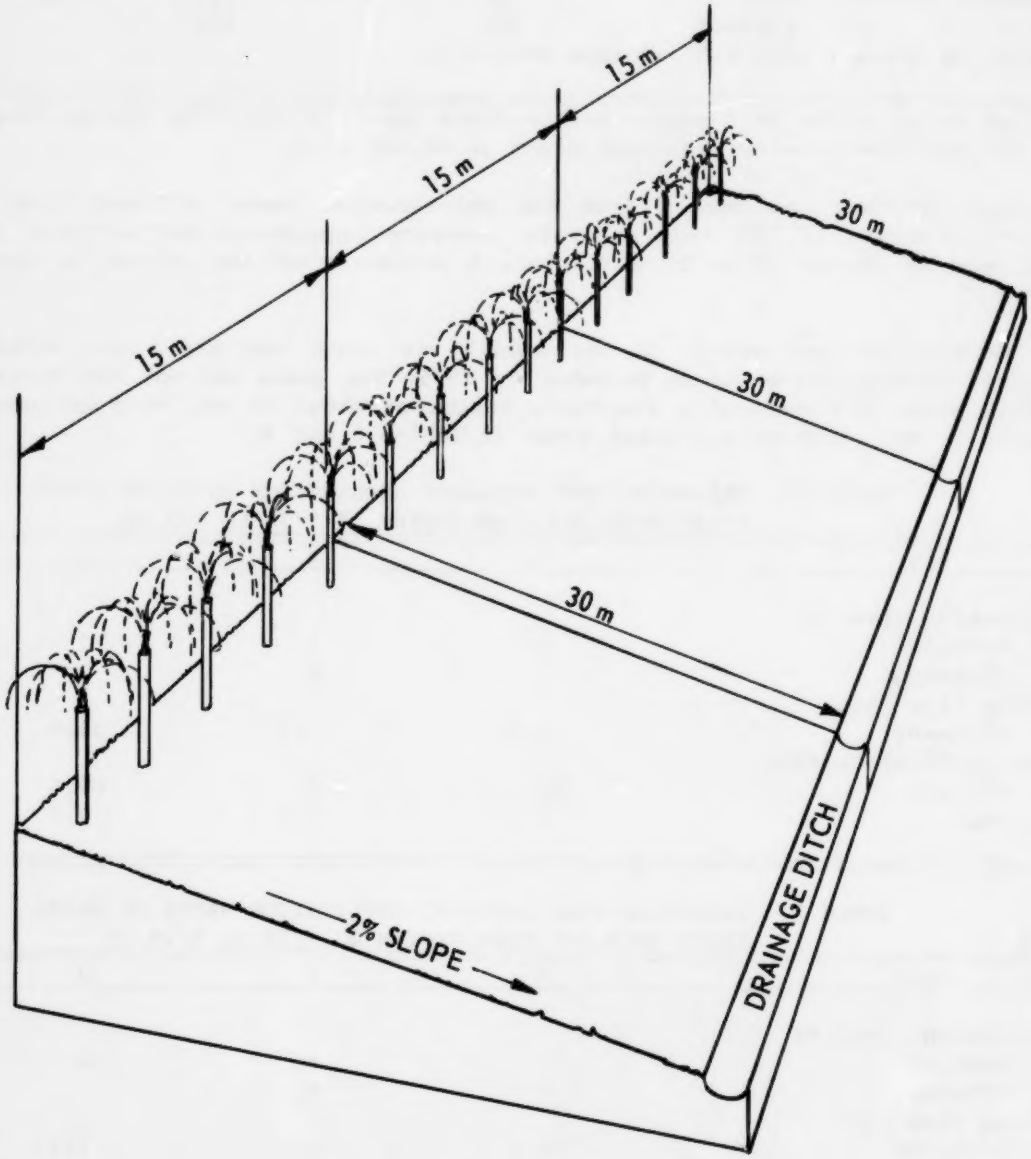

15 m
15 m
15 m
30 m
30 m
30 m
2% SLOPE
DRAINAGE DITCH

Figure 2. Schematic of Davis Pilot Overland Flow Site.

Effluent quality from the overland flow systems was satisfactory, and the ability to meet the standard of 30 mg/L suspended solids and BOD_5 was demonstrated. As the grass cover crop matures and thickens the overland flow system performance should improve. Since the pilot study covered a relatively short time period, the results shown in Tables 4 and 5 should be considered a conservative estimate of process performance.

TABLE 4. MONTHLY AVERAGE EFFLUENT SUSPENDED SOLIDS VALUES AT DAVIS, mg/L

		Effluent loading rate cm/d					
Month*	Influent	0.7	1.2	2.0	3.0	4.1	5.3
November	82	29	30	33			
December	64	19	18	25			
January	59	11	14	18			
March	59				22	30	31

*Change of loading rate occurred in mid-February.

TABLE 5. MONTHLY AVERAGE BOD_5 VALUES AT DAVIS, mg/L

		Effluent loading rate, cm/d					
Month*	Influent	0.7	1.2	2.0	3.0	4.1	5.3
November	73	20	13	21			
December	47	11	15	20			
January	41	11	11	15			
March	42				18	27	24

*Change of loading rate occurred in mid-February.

Conclusions stated in the pilot study report included:

- Hydraulic loading rates up to 210 m^3/ha-d are suitable for process design.
- Rye grass would be a suitable cover for a prototype system.
- Chlorinated effluent will not damage the grass.
- Data obtained are conservative estimates of eventual process performance because the microbial population and surface thatch had minimum opportunity to develop. The time required to develop optimum microbial population and surface thatch is not known, but the study team felt there could be improvement.
- The effect of precipitation could not be predicted because the studies were carried out during an extreme drought.

Construction of the Davis overland flow system is scheduled to begin in Spring, 1980. Design has been completed by Brown and Caldwell Consulting Engineers, land acquisition is in progress, and the contracts were advertised for bids on December 6, 1979. The low bid was $1,976,900. The general design plan is to pump chlorinated effluent from the existing oxidation ponds to an 81-ha area having a 69 net ha overland flow application area. Chlorination was provided ahead of the overland flow system so that dechlorination requirements prior to discharge could be minimized. (Some dechlorination will occur as the wastewater travels down the slope). Treated effluent will continue to be discharged to Willow Slough Bypass.

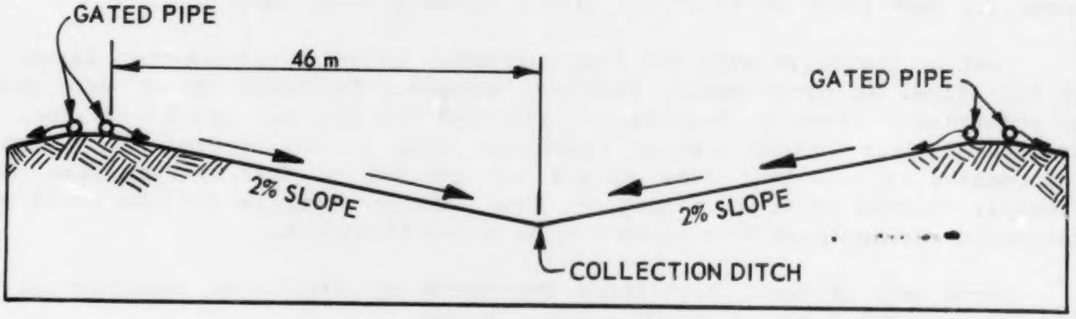
Storage of the wastewater will not be necessary because the treatment process will be operational throughout the year. Equalization storage is provided in the oxidation ponds to allow continuous application of wastewater during the summer months. At the present time, evaporation losses from the ponds exceed inflow for two or more months per year, thus water levels in the oxidation ponds will drop considerably in the late summer.

The overland flow system has been designed using the following criteria shown in Table 6. The system will be divided into 15 zones, each consisting of 2 overland flow terraces and extending from the centerline of one collection ditch to the next collection ditch. Zones will be 92-m wide and approximately 500-m long. A flow diagram of the entire treatment system is shown in Figure 3. Effluent from each terrace is collected and either pumped into Willow Slough Bypass or recycled. Recycling will allow grass maintenance during extreme drought periods.

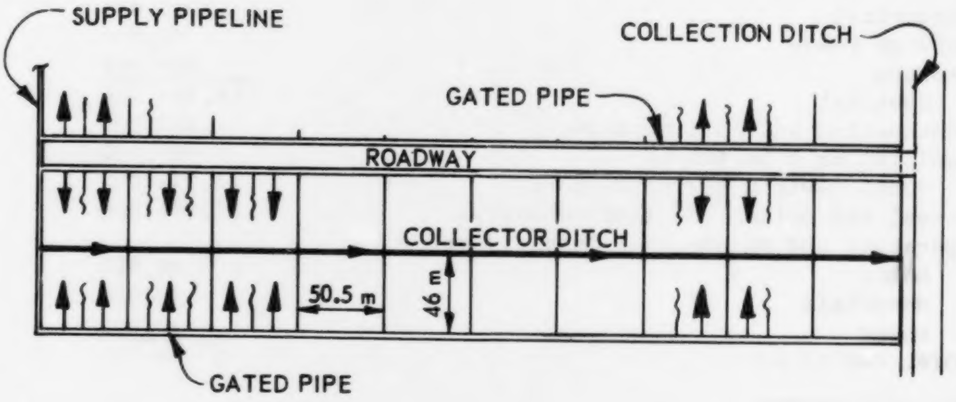
TABLE 6. CITY OF DAVIS SYSTEM (under construction)

Type of wastewater	Domestic Sewage
Capacity	19,000 m^3/da
Land area	69 ha
Preapplication treatment	Comminution, grit removal, primary sedimentation, oxidation ponds
Disinfection	Chlorination prior to application
Storage	None
Soil type	Clay and silty clay
Application	Gated pipe
Control method	Butterfly line control valve
Cover crop	Mixture of grasses; fescue and rye
Slope	2%
Application	15 cm/wk
Application period	4-12 hr/da
Annual rainfall	42 cm/yr
Temperature,	
Ave Max, summer	35°C
Ave Min, winter	4°C
Evapotranspiration	130 cm/yr
Class A pan evaporation	173 cm/yr
Discharge requirements	
Suspended solids	30 mg/L (ave)
BOD_5	30 mg/L (ave)

The distribution system will consist of 0.25-m gated, aluminum irrigation pipe. Five-cm slide gates will be set on 0.6-m centers. The irrigation pipes will rest on a 2-m wide rock and gravel bed at the head of each terrace. Pipes


GATED PIPE
46 m
GATED PIPE
2% SLOPE
2% SLOPE
COLLECTION DITCH

CROSS SECTION
(1 of 10 areas)


SUPPLY PIPELINE
COLLECTION DITCH
GATED PIPE
ROADWAY
COLLECTOR DITCH
50.5 m
46 m
GATED PIPE

PLAN VIEW
(1 of 10 areas)

Figure 3. City of Davis, schematic of new overland flow system.

will come off a 0.6-m header and flow in each distribution pipe will be controlled by a butterfly line control valve.

Chlorinated oxidation pond effluent will be pumped to the header with two-12.5 m^3/min pumps rated at a dynamic head of 5.6 m. The two effluent/recycle pumps are each rated at 10 m^3/min with a 8.2-m dynamic head.

Cost of the Davis overland flow suspended solids removal system is not known at this time. As noted above, contract documents for construction were released to potential bidders on December 6, 1979 and the low bid was $1,976,900. Costs associated with preapplication treatment need to be determined. Available information on overland flow allows the conclusion that system size is not linearly related to organic loading. Thus, design criteria for the Davis system cannot be extrapolated to systems having no pretreatment.

Brown and Caldwell Consulting Engineers estimated the construction costs (based on an ENR Index of 3200) as shown below:

Item	Estimated Cost
Gravity line to sump	$ 55,000
Distribution and runoff collection sump	45,000
Terrace construction	250,000
Distribution system	290,000
Distribution pumping	290,000
Runoff collection	30,000
Electrical	45,000
Service roads	70,000
Fencing	120,000
Subtotal	$1,195,000
Engineering and contingencies	420,000
Land (81 ha @ $4,400/ha)	360,000
TOTAL CAPITAL ESTIMATED COST	$1,975,000
Actual bid price (w/o land or engr.)	$1,976,900
Operation and Maintenance Costs (1 yr)	
Labor	$ 48,000
Materials	10,000
Power	30,000
TOTAL O&M (1 yr)	$ 88,000

Labor is estimated at 2.3 man-years/year of staff time to operate the overland flow system. In addition, the Consultant assumed that heavy maintenance would be contracted to outside specialists, and that harvesting of the grass would be done by City employees or local farmers at nominal cost. These costs are presented in Section III.

Research Facility

Four of the overland flow system terraces have been modified to allow their use as an experimental facility. Each of the terraces is divided into 10 subterraces each 50-m wide. Two of the terraces are used to treat 950 m^3/d of comminuted raw wastewater and the other two slopes to treat 950 m^3/d of primary effluent. Both wastewaters are conveyed via surface aluminum pipe to gated aluminum pipe distribution laterals. Flow onto each 50-m experimental unit is metered and controlled by a manual valve. Flow from the units is collected, metered by weirs, and discharged to the main collection channel.

The field studies are part of a pilot and demonstration project supported by the California State Water Resources Control Board and conducted by the Department of Civil Engineering of the University of California, Davis. The Principal Investigators for the project are E.D. Schroeder and George Tchobanoglous and the work is under the direct supervision of Robert G. Smith. Pilot studies began in fall, 1978 with the objectives of identifying the design and operating parameters that govern overland flow process performance and developing functional design relationships.

The pilot facilities initially financed by Campbell Soup Company are located indoors and consist of three beds, each 1.5-m wide, 6-m long, and 0.2-m deep. Light at a surface intensity of 27,000 lx is provided from light banks made up of very high output fluorescent and 100 watt incandescent bulbs that operate 14 hr/d. Evapotranspiration is monitored using an adjacent, 1.2-m diameter hydraulic pillow lysimeter subjected to the same light intensity. Clay soil was obtained from the Davis overland flow system site and a bermuda grass sod was used as the cover.

Parameters varied in the study have included bed slope, application time period per day, application rate per unit of slope width, application frequency, hydraulic loading rate, organic loading rate and nitrogen loading rate. Fecal coliform removal was examined in a separate study using the same facilities.

Initial studies were conducted using a soluble synthetic wastewater composed of Bactopeptone, sucrose, ammonium chloride, potassium phosphate and tap water. The BOD_5 and TOC concentrations were approximately 145 and 95 g/m^3, respectively. Following completion of these studies, experiments were conducted using primary effluent obtained daily from the Davis treatment plant.

Bed slope was varied from 2 to 6 percent without a measurable effect on rate of organic removal down the bed. Similar results were obtained by varying hydraulic loading rate up to 15 cm/wk. Loadings of 30 cm/wk resulted in significantly decreased organic removal rates.

Experiments using City of Davis primary effluent were begun in October, 1979. Wastewater BOD_5 and TOC concentrations have been in the ranges of 60 to 80 mg/L and 40 to 50 mg/L, respectively. Results to date (December, 1979) have been very similar to those obtained for the soluble substrate. In general, organic removal can be described by a function of the form:

$$\frac{C_z}{C_o} = e^{-Kz/Q} \quad (1)$$

where C_z = Organic mass concentration a distance z down the slope, $\frac{\text{mass}}{\text{volume}}$

C_o = Organic mass concentration of the application point, $\frac{\text{mass}}{\text{volume}}$

Q = Volumetric flow rate, volume/time

K = Rate coefficient with units dependent on a α
α = Emperically determined coefficient

Removal of fecal coliforms and nitrogen have also been studied using the pilot facilities. This work will be complete in June, 1980. Progress to date has been reported in Reference 2. Conclusions thus far are as follows:

- Differences in slopes within the 2 to 6 percent range do not have a significant impact on organic removal rate.
- For a given hydraulic loading rate, a lower application rate will result in a higher organic removal rate.
- At the same application rate, the hydraulic loading rate has little effect on the organic removal rate in the range of 10 to 15 cm/wk/30 m. When the hydraulic loading rate is increased to 30 cm/wk/30 m, the organic removal rate decreases. Whether this phenomenon is caused by the high hydraulic loading rate or the correspondingly high organic loading rate is not known.

Industrial Treatment

Current data are limited for the Hunt-Wesson project. The site was visited and the observations made were favorable. The effluent stream showed no significant objectionable color or turbidity. There were no odors apparent. The grasses grown appeared hardy and lush. Hunt-Wesson operates the facility only during the canning season. Application rates are 9-12 cm/wk. Evapotranspiration accounts for more than one half of the applied flow. Site characteristics are presented in Table 7.

TABLE 7. HUNT-WESSON SITE CHARACTERISTICS

Type of wastewater - tomato cannery wastes
Capacity - 15,000 m^3/d
Land area - 69 ha
Pretreatment - screening
Disinfection prior to treatment - none
Storage - none (usual operation July through September)
Soil type - silty clay and clay
Application method - solid set sprinkler
Control methods - automatic air-controlled valves and time clocks
Crop - Mixed grasses including, fescue, trefoil, reed canary, and annual rye grass
Slope - 2.5 percent
Application rate - 9 cm/wk
Application period - 6-10 hrs/d for 6 days/wk
Yearly Rainfall - 42 cm/yr
Temperature
  Ave Max - 32°C
  Ave Min - 4°C

ADA, OKLAHOMA

Ada, OK is the location of the Robert S. Kerr Environmental Research Laboratory (RSKERL). This facility has been the center of land treatment research and study for the US EPA. Overland flow systems have been studied at the Lab's field site as well as at off-site facilities. The on-site system characteristics are shown on Table 8.

TABLE 8. ADA SITE CHARACTERISTICS

Type of wastewater - domestic sewage
Capacity - 790 m^3/d
Land area - 3.2 ha
Pretreatment - screened or primary sedimentation and oxidation pond
Disinfection prior to application - no
Storage - none
Soil type - clay
Application method - rotating spray boom, fixed riser with fan nozzle
Control methods - electrically actuated gate valves and time clocks
Crop - Kentucky 31 fescue, annual rye grass and bermuda grass
Slope - 2 percent
Application rate - 15-23 cm/wk
Application period - 8-12 hr/d
Yearly rainfall - 100 cm/yr
Temperature
    Ave Max - >10°C
    Ave Min - > 0°C

The climate at Ada is normally mild, with temperature minimums averaging above freezing except during January when the average minimum is -1°C.[3] Daily maximum temperatures consistently exceed 10°C. Average annual precipitation is about 100 cm.

Research emphasis at Ada has been placed on minimizing the degree of pretreatment. Studies of overland flow treatment have been conducted using raw wastewater, primary effluent, and pond effluent. The principal goal has been to demonstrate satisfactory performance of a system with minimal complexity and minimal operating cost. This objective is especially important to small communities that are required to upgrade pond systems. Treatment levels better than secondary were obtained in early work[3] utilizing overland flow for treatment of raw domestic wastewater. Results, reported separately for winter and summer operations, are summarized in Table 9. Loading rates were varied with 9.8 cm/wk being the highest rate reported.

TABLE 9. MEAN WASTEWATER CHARACTERISTICS*, mg/L

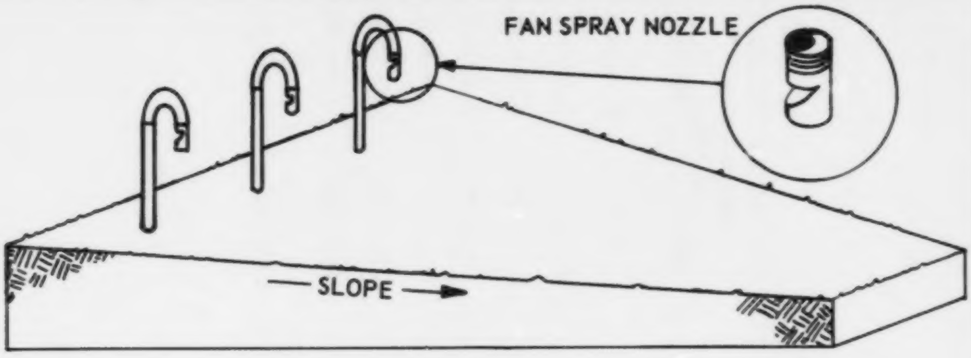
Parameter	Raw wastewater	Effluent	
		Summer	Winter
Suspended solids	160	8	9
BOD	150	7	8
COD	314	58	46
Total nitrogen	23.6	2.2	6.8
Kjeldahl nitrogen	22.8	1.7	2.9
Ammonia	17.0	0.6	1.3
Nitrate & nitrite	0.8	0.4	3.7
Total phosphorus	10.0	4.3	5.1

*9.8 cm/wk loading rate used for this test

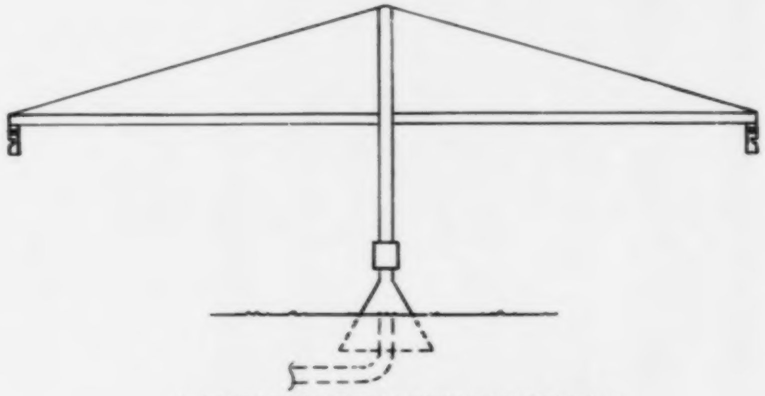
A second study considered treatment of raw wastewater by overland flow with improved phosphorus removal by alum addition[4]. Additions of 1.5 to 2.0 mg alum/mg phosphorus resulted in effluent phosphorus concentrations less than 2 mg/L and corresponded to a 85 percent removal. Other constituent removals were essentially the same as shown in Table 9.

A third RSKERL report provides the results of work done at Pauls Valley, OK. This work consisted of overland flow treatment of both raw sewage and oxidation pond effluent. The system consists of 32 terraces, each having an area of 0.1 ha. Screened raw wastewater is applied to 24 cells with pond effluent applied to the remaining 8 cells. The slopes used are 2% and 3%. Terrace dimensions are 23 m wide by 46 m long. Three types of distribution systems are used. They are fixed fan nozzles, rotating boom with fan nozzles, and bubbling orifices. These are shown by schematic in Figure 4.

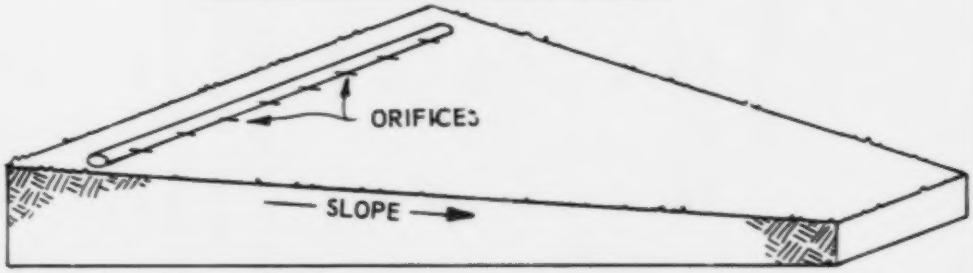
Temperature effects on operations were particularly noticeable and are summarized in Table 10. Fecal coliform reductions were less than one order of magnitude. Sub-freezing temperatures hampered BOD_5 and ammonia removals. Treatment of pond effluent by overland flow resulted in limited improvement of removals of the constituents measured. Results are in Table 10. Detailed comparisons of factors imparting process performance are shown on Tables 11, 12, 13, and 14.


FAN SPRAY NOZZLE
SLOPE

a. FIXED FAN SPRAY



b. ROTATING BOOM WITH FAN NOZZLE


ORIFICES
SLOPE

c. PIPE WITH ORIFICES

Figure 4. Schematics of distribution systems used at Pauls Valley.

TABLE 10. **WASTEWATER CHARACTERISTICS AT PAULS VALLEY, mg/L**

Parameter	Raw wastewater		Overland flow effluent*		Pond effluent		Overland flow effluent†	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Suspended solids	105	90.7	3.6-10.6	11.0-15.6	114	26.1	60.9-101	6.33-19.9
BOD	117	130	8.3-21.0	24-42.1	27.7	16.2	18.6-25.0	9.30-17.2
Nitrate as N	<0.05	0.04	0.16-1.04	0.19-0.74	0.08	0.06	0.10-0.29	0.15-0.94
Ammonia as N	16.7	16.5	3.1-6.9	6.89-13.4	1.70	13.5	0.21-0.48	8.41-11.0
Organic nitrogen	8.5	7.28	2.9-5.0	2.66-4.01	13.8	3.93	9.1-14.0	2.24-4.04
Total phosphorus	8.3	8.46	7.9-9.2	6.87-9.64	6.31	12.1	4.21-5.87	10.1-10.9
Fecal coliform (MPN/100 ml)	$5\text{x}10^6$	$3.9\text{x}10^6$	$4.8\text{-}18\text{x}10^5$	$1.0\text{-}2.4\text{x}10^6$	$3.3\text{x}10^4$	$6.0\text{x}10^4$	$1.6\text{-}10\text{x}10^4$	$1.8\text{-}6.4\text{x}10^4$

*From overland flow treatment of raw wastewater.

†From overland flow treatment of pond effluent.

TABLE 11. AVERAGE RESULTS AND SIGNIFICANT DESIGN FACTORS FROM THE RAW SYSTEM FOR THE WINTER APPLICATION AT PAULS VALLEY - NOVEMBER 28, 1977 - MARCH 10, 1978

		Application method							
		Riser		Trough		Boom			
Anal. par.	% Slope	Eff. conc.	% Red.	Eff. conc.	% Red.	Eff. conc.	% Red.	Infl. conc.	Significant factors in performance
BOD mg/L	3	37.7	71	39.1	70	24.0	82	130	Slope
	2	42.1	68	40.4	69	39.8	69		
Sus. Solids mg/L	3	15.6	83	11.0	88	12.1	87	90.7	None
	2	11.2	88	11.9	87	12.0	87		
Fecal Coliform per 100 ml	3	1.5×10^6	62	1.2×10^6	69	2.3×10^6	41	3.9×10^6	Appl. Mtd.
	2	1.3×10^6	67	1.0×10^6	74	2.4×10^6	38		
Total P mg/L	3	7.55	11	6.87	19	9.55	-13	8.46	Appl. Mtd.
	2	7.64	10	7.75	8	9.64	-14		
NO_3 N mg/L	3	0.24		0.21		0.74		0.04	Appl. Mtd.
	2	0.19		0.26		0.44			
NH_3 N mg/L	3	6.89	58	8.47	49	11.4	31	16.5	Appl. Mtd
	2	9.56	42	8.56	48	13.4	19		
Org. N mg/L	3	3.47	52	3.65	50	2.66	63	7.28	None
	2	4.01	45	3.64	50	3.12	57		

TABLE 12. AVERAGE RESULTS AND SIGNIFICANT DESIGN FACTORS FROM THE RAW SYSTEM FOR THE SUMMER APPLICATION AT PAULS VALLEY - MARCH 20, 1978 - OCTOBER 27, 1978

		Application method							
		Riser		Trough		Boom			
Anal. Par.	% Slope	Eff. conc.	% Red.	Eff. conc.	% Red.	Eff. conc.	% Red.	Infl. conc.	Significant factors in performance
BOD mg/L	3	14.2	88	21.0	82	8.6	93	117	Appl. Mtd.
	2	18.2	84	18.3	84	8.3	93		
Sus. Solids mg/L	3	9.4	91	10.6	90	3.6	97	105	Slope Appl. Mtd.
	2	6.4	94	6.6	94	3.6	97		
Fecal Coliform per 100 ml	3	1.4×10^6	72	1.8×10^6	64	1.2×10^6	76	5.0×10^6	Slope
	2	1.2×10^6	76	1.2×10^6	76	4.9×10^5	90		
Total P mg/L	3	7.9	5	8.5	-2	9.2	-11	8.3	Appl. Mtd.
	2	8.7	-5	8.9	-7	9.2	-11		
NO_3 N mg/L	3	0.18		0.16		1.04		<0.05	Appl. Mtd. Interact.*
	2	0.18		0.24		0.67			
NH_3 N mg/L	3	4.2	75	7.4	56	3.1	81	16.7	Slope Appl. Mtd. Interact.
	2	6.9	59	6.9	59	3.4	80		
Org. N mg/L	3	4.0	53	4.8	44	2.9	66	8.5	Slope Appl. Mtd.
	2	4.6	46	5.0	41	3.1	64		

*Interaction between slope and application method.

TABLE 13. AVERAGE RESULTS AND SIGNIFICANT DESIGN FACTORS FROM THE SECONDARY SYSTEM FOR THE WINTER APPLICATION AT PAULS VALLEY - NOVEMBER 28, 1977 - MARCH 10, 1978

		Application method					
		Riser		Trough			
Anal. Par.	% Slope	Eff. conc.	% Red.	Eff. conc.	% Red.	Infl. conc.	Significant factors in performance
BOD	3	13.8	15	17.2	-6	16.2	Slope
mg/L	2	9.30	43	9.40	42		
Sus. Sol-	3	15.7	40	19.9	24	26.1	Slope
ids mg/L	2	6.67	74	6.33	76		
Fecal Coli-	3	4.5×10^4	25	6.4×10^4	-7	6.0×10^4	Slope
form per 100 ml	2	2.5×10^4	58	1.8×10^4	70		
Total P	3	10.4	14	10.9	10	12.1	None
mg/L	2	10.7	12	10.1	17		
NO_3	3	0.57		0.15		0.06	Slope
N mg/L	2	0.94		0.60			Appl. Mtd.
NH_3	3	8.41	38	10.8	20	13.5	
N mg/L	2	11.0	19	9.28	20		Interact.
Org. N	3	2.81	28	4.04	-3	3.93	Slope
mg/L	2	2.42	38	2.24	43		

TABLE 14. ANALYTICAL RESULTS AND SIGNIFICANT DESIGN FACTORS FROM THE SECONDARY SYSTEM, FOR THE SUMMER APPLICATION AT PAULS VALLEY - MARCH 20, 1978 - OCTOBER 27, 1978

		Application method					
		Riser		Trough			
Anal. Par.	% Slope	Eff. conc.	% Red.	Eff. conc.	% Red.	Infl. conc.	Significant factors in performance
BOD mg/L	3	18.7	32	25.0	10	27.7	
	2	19.8	29	18.6	33		Interact.
Sus. Solids mg/L	3	60.9	47	101	11	114	
	2	63.0	45	66.3	42		Appl. Mtd.
Fecal Coliform per 100 ml	3	9.3×10^4	-182	1.0×10^5	-203	3.3×10^4	None
	2	1.6×10^4	52	1.9×10^4	42		
Total P mg/L	3	4.21	33	4.62	27	6.31	Slope
	2	5.87	7	5.60	11		
NO_3 N mg/L	3	0.10		0.13		0.08	None
	2	0.29		0.17			
NH_3 N mg/L	3	0.21	88	0.27	84	1.70	Slope
	2	0.48	72	0.44	74		
Org. N mg/L	3	10.5	24	14.0	-1	13.8	Slope
	2	9.1	34	9.4	32		Appl. Mtd. Interact.

UTICA, MISSISSIPPI

The overland flow facility at Utica is a small, continuously operating research site treating 76 m^3/d of lagoon effluent. Research at this site was carried out by the Corps of Engineers in cooperation with the EPA. Design characteristics are summarized in Table 15. The facility was designed to allow investigation of a variety of treatment modes. There are twenty-four, 4.6 x 46-m plots, plot slopes of 2, 4 and 8 percent are used (8 plots at each slope). Rate of flow and duration of application are automatically controlled to each of the 24 beds. This experimental system allows observation of duplicate modes of operation at different slopes. Photos of the site are shown in Figure 5. Results of the studies have been reported in Reference 5.

TABLE 15. UTICA OVERLAND FLOW SITE CHARACTERISTICS

Type of wastewater - domestic
Capacity - 76 m^3/d
Land area - 0.5 ha
Pretreatment - facultative oxidation pond
Disinfection prior to application - none
Storage - none
Soil type - silty, clayey loam
Application method - perforated trough
Control methods - electric timed solenoid valves
Crop - mixed grasses (reed canary, Kentucky 31 tall fescue, perennial rye grass, common Bermuda)
Slopes - 2, 4 and 8 percent
Application rates - 6.5-18 cm/wk
Application period - 6, 8, 18, 24 hr/d at 5 and 7 d/wk
Yearly rainfall - 137 cm
Temperature
  Ave Max - 24°C
  Ave Min - 12°C

A variety of grasses is grown on each plot including reed canary, fescue, perennial rye grass and common Bermuda. Grass is harvested three to four times a year to prevent shading of short varieties. Crop yields have been similar to grass production obtained on better agricultural soils (11,700 kg/ha-yr for reed canary at 6.5 cm/wk and 10,000 kg/ha-yr for overseeded rye grass at both 6.5 and 18 cm/wk). The same annual yield has been obtained for either three or four cuts. By regular harvesting and by mixing the grasses, the researchers can maintain a dense mat of vegetation conducive to the bacterial growth required for wastewater treatment.

A trough with a perforated bottom is used to evenly distribute wastewater across the top of each berm. Flow from the trough can be varied from 3.5 to 21.2 m^3/hr. Application times are controlled by electrically timed solenoid valves. Periods of 6, 18, and 24 hr have been used on both a 5- and 7-day week basis. The hydraulic loading rate has been varied between 1.27 and 5.08 cm/d.

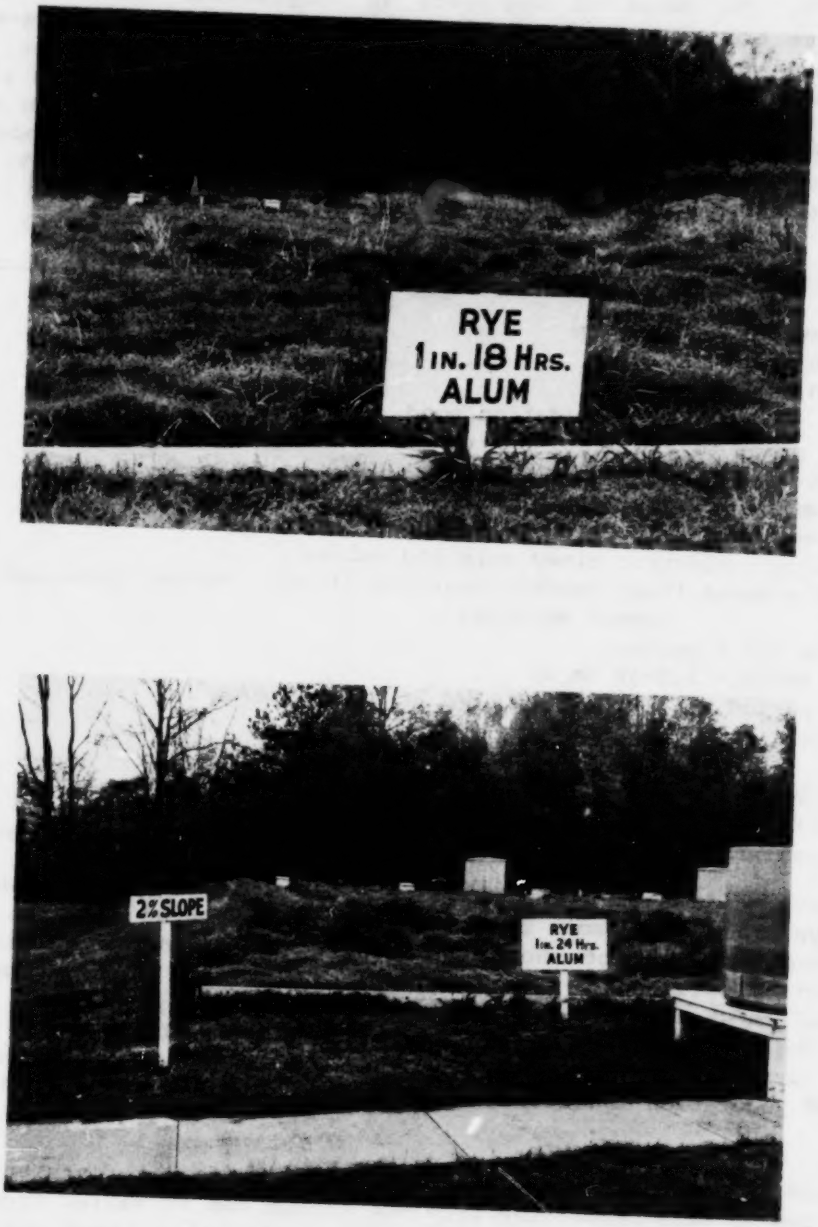

RYE
1 IN. 18 HRS.
ALUM
2% SLOPE
RYE
1 in. 24 Hrs.
ALUM

Figure 5. Utica, Mississippi Overland Flow Site.

Application continues throughout the winter but at reduced flow rates. No storage is provided. Wastewater is pretreated in a 2.4-ha facultative pond. Effluent from the pond contains significant amounts of algae which make up the bulk of the suspended solids being applied to the overland flow site. The influent is low in soluble nitrogen, phosphorus and heavy metals so these elements are added at the site for research purposes. Pond effluent characteristics are shown in Table 16.

TABLE 16. OXIDATION POND EFFLUENT CHARACTERISTICS AT UTICA

Parameter	Range	Average
BOD_5, mg/L	6-37	22
SS, mg/L	8-75	35
Total N, mg/L	-	20*
Total P, mg/L	5-15	10§
Fecal coliforms/100 ml		
summer	5,000-12,000	5,000
winter	600-8,000	1,000
Cu, mg/L	-	0.10#
Ni, mg/L	-	0.10#
Cd, mg/L	-	0.05#
pH	7-11	-

* Additional Nitrogen added as NH_4Cl, $NH_4H_2PO_4$

§ Additional Phosphorus added as $NH_4H_2PO_4$

# Added

Mosquitos have not been a problem at the Utica facility. The researchers have maintained flowing water and eliminated depressions where ponding and breeding of mosquitoes can occur. The facility has been in operation since 1971 and during the first year of operation, research was effectively curtailed by an invasion of army worms that consumed the entire grass crop. This problem occurred throughout the Utica locality, but was eliminated and has not occurred again.

Research Results

Parameters investigated included: BOD and suspended solids removal, nutrient and heavy metal removal, and fecal coliform removal. Removals of BOD and SS were not affected by slope. Typical performance values are presented in Table 17.

TABLE 17. TREATMENT RESULTS AT UTICA - 1976-1977

Parameter	Lagoon effluent ave mg/L	Hydraulic loading cm/wk	Slope percent	Removals percent
BOD, mg/L	22	6.5	2, 4, 8	55
SS, mg/L	35	6.5	2, 4, 8	57
Fecal Coliforms/100 ml				
summer	5,000	6.5	-	(net increase recorded)
winter	1,000	6.5	-	50
		18.0	-	80

The bulk of the Utica research involved nutrient removals. Nitrogen removal was found to vary seasonally. During most of the year about 90 percent removal was obtained on all slopes for wastewater applied at 6.5 cm/wk. During the winter, nitrogen removals dropped significantly, with the greatest nitrogen removal occurring on the 8 percent slope. At higher rates of application, (18 cm/wk) nitrogen removals were similar to those at lower rates of application. Results are summarized in Table 18.

TABLE 18. PERCENT NITROGEN REMOVALS AT UTICA - 1976-1977

Hydraulic loading cm/wk	Application period hr	Percent slope 2 summer	2 winter	4 summer	4 winter	8 summer	8 winter
6.5	6	90	75	91	78	90	80
18	6	-	45	-	-	-	-
18	18	80	-	-	-	-	-

* Additional nitrogen added as NH_4Cl, $NH_4H_2PO_4$

Phosphorus removal was greater for wastewater applied at 6.5 cm/wk than that applied at 18 cm/wk. However, when the application duration was increased from 6 hr to 18 hr, removals were similar for both hydraulic loadings. Alum addition resulted in significantly increased phosphorus removal. Effluent phosphorus concentrations as low as 1.0 mg/L resulted from dosages of 1:1, Al:P. Phosphorus removals are shown in Table 19.

TABLE 19. PERCENT PHOSPHORUS REMOVAL AT UTICA - 1976-1977

Hydraulic loading cm/wk	Application period hrs	No alum added fall	No alum added winter	1:1 Al:P summer	Alum added spring
6.5	6	50	40	85	50
18	18	40	25	85	50

Heavy metal removals up to 90 percent have been observed at Utica. The accumulation of heavy metals in plants and soil has not yet been investigated.

Design Recommendations By Utica Researchers

Hydraulic loading rates should be chosen as a function of the discharger requirements. Loadings in the range of 6.5 to 18 cm/wk with a 6-hr/d application on a 5-day week basis have resulted in effluent BOD_5 and suspended solids concentrations of less than 20 mg/L each. Differences were not detectable for slopes of 2 to 8 percent. Lower slopes can result in local depressions and ponding, while higher slopes require more grading and may be financially less feasible. Mixed grasses and regular harvesting are essential for production and maintenance of a dense vegetative mat. Occasional mulching of grasses may be helpful in some areas.

CARBONDALE, ILLINOIS

Carbondale, IL is the site of small, full-scale operation where overland flow is used to treat pond effluent. This facility treats domestic wastewater from the Cedar Lane Trailer Court. Cedar Lane Trailer Court is a small, 54 unit mobile home park located 3 km south of Carbondale. The terrain is slightly rolling and the park is wooded. The population of the Cedar Lane Trailer Court is 135, and has been relatively stable since construction in the 1950's.

Prior to the development of the present overland flow system, in 1976, the park's sewage was treated in two, 38-m^3 septic tanks followed by a 0.28 ha oxidation pond located approximately 20 m from the nearest trailer. A partial view of the oxidation pond and the trailer park is shown in Figure 6.

Figure 6. Cedar Lane Trailer Park oxidation pond.

Effluent from the oxidation pond did not meet the discharge requirements of the Illinois Environmental Protection Agency Pollution Control Board (Table 20).

TABLE 20. STATE OF ILLINOIS WATER QUALITY STANDARDS[6]

pH: Within range of 6.5 to 9.0 except for natural causes.

BOD_5: Average BOD_5 shall not exceed 4 mg/L on intermittent streams*

Phosphorus: Shall not exceed 0.05 g/m^3 as P in any reservoir or lake or in any stream at the point where it enters any reservoir or lake.

Dissolved oxygen: Shall not be less than 6.0 g/m^3 during at least 16 hr of any 24-hr period, nor less than 5.0 g/m^3 at any time.

Ammonia nitrogen: Shall not exceed 1.5 mg/L as N.

Nitrite plus nitrate: Shall not exceed 10.0 mg/L as N for public and food processing water supply.

* The receiving stream is an intermittent stream.

Preliminary Treatment

Characteristics of the septic tank effluent have not been monitored. The oxidation pond effluent characteristics were monitored during 1976 and 1977[7,8] and are presented in Table 21.

TABLE 21. OXIDATION POND EFFLUENT CHARACTERISTICS AT CEDAR LANE[9]

Parameter	Range of values
BOD_5, mg/L	30 - 110
Suspended solids, mg/L	20 - 60
Phosphorus, mg/L	3 - 4
Ammonia nitrogen, mg/L	20 - 40
Nitrate and nitrite nitrogen, mg/L	0
Fecal coliforms, MPN/100 ml	Approx. 35,000

During the 1976-77 research program, maximum ammonia nitrogen concentrations were desired in the pond effluent. Duckweed was allowed to predominate on the pond surface to minimize algal growth and prevent nitrification. This was done to maximize organic and nitrogen loadings on the overland flow facility. Since July, 1977, the pond has been operated without effluent monitoring.

Oxidation pond effluent flows into a 3.8 m^3 cylindrical tank from which it is pumped through 90 m of 5-cm plastic pipe to the top of a grassy slope approximately 7-m in elevation above the pond. The overland flow slope is shown in Figure 7. The pump is submersible and is operated by a float activated switch.

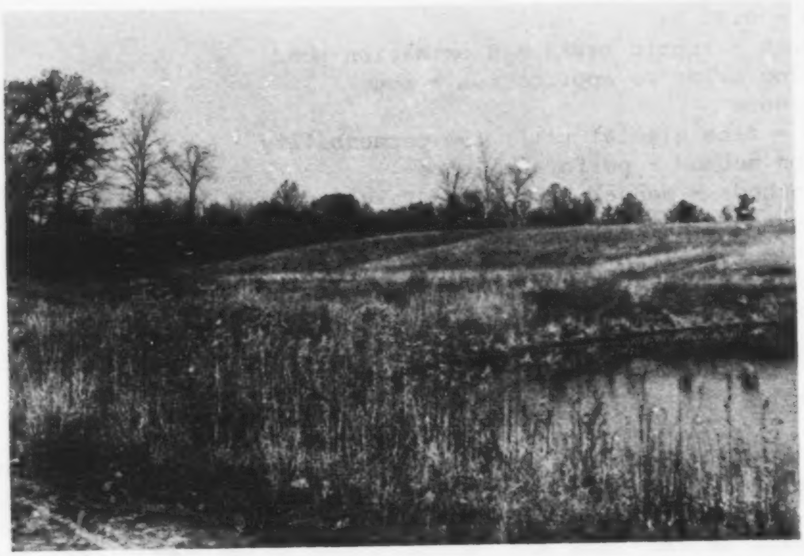


Figure 7. Overland flow slope at Cedar Lane Trailer Park.

Overland Flow Site

The overland flow slope runs for approximately 30 m at 7 percent, at which point the slope increases to approximately 12 percent for an additional 30 m and then flattens out. A small channel that eventually discharges into Drury Creek is about 40 m from the base of the 12 percent slope. Flow in the channel is intermittent and consists of runoff from the small surrounding watershed.

Soil in the area is a fine granular glaciated material with low permeability. Runoff from the slopes accounted for over 80 percent of the applied wastewater.

The site available for overland flow was approximately 90 m wide. A 10-m section near one edge was chosen for the system. This section is shown as the darker portion near the left edge of the slope in Figure 7. Tall fescue was the predominant grass on the slope and has remained so since wastewater application began. Site characteristics are summarized in Table 22.

TABLE 22. CARBONDALE SITE CHARACTERISTICS

Type of wastewater - domestic sewage
Capacity - 38 m^3/d
Land area - 0.06 ha
Pretreatment - septic tanks and oxidation pond
Disinfection prior to application - none
Storage - none
Soil type - fine glacial till, low permeability
Application method - perforated pipe
Control methods - manual throttling valve on pump, intermittent flow
Crop - natural grasses
Slope - 7-12 percent
Application rate - 44 cm/wk
Application period - 0-24 hr/d

System Design

The site consists of two 5-m x 60-m sections. Aluminum garden edging was inserted along the boundaries of the overland flow system to contain the flow. The upper 30-m (the 7 percent slope section) was divided into two, 5 x 30-m portions. Grass on one side was maintained at a height of less than 30 cm during the research while the other was allowed to grow unchecked. Following completion of the research project in June, 1977, the entire system was not cut until November, 1979, shortly before the site visit.

Two distribution systems were used during the 1976-77 research project; the initial system at the top of the slope and a redistribution system at the end of the first 30-m. The latter system was essentially the same as the intial system. It fell into disuse following the completion of the research, probably due to lack of maintenance of the header boards used to channel flow to the distribution box.

The distribution system at the top of the slope consists of a distribution box and two, 5-m long, perforated 10 cm distribution pipes. Perforations are on 30 cm centers and are approximately 1 cm in diameter. Flow into each pipe is controlled by a V-notch weir in the distribution box. Equal flows are maintained to each distribution pipe.

During the 1976-77 studies, a range of application rates and periods were used. One finding was that continuous application (24 hr/d) had no negative effects for operating periods of several weeks. Since the end of the study, application has been controlled by the oxidation pond levels through use of the float activated switch. Thus, wastewater may be applied to the overland flow systems for several days on a 24-hr basis, followed by a period with no wastewater application. Length of periods depends on flow into the pond and seasonal evaporation rates.

During the 1976-77 studies, samples were taken from the influent, at 15-, 30-, and 60-m points and in the receiving channel upstream and downstream of the overland system. Flow was monitored with weirs in the distribution box and in the channel at points both upstream and downstream of the discharge. Since July, 1977, sampling has been the minimum required by the Pollution Control Board.

Suspended solids and BOD_5 samples were taken on a weekly basis in 1976-77. Nutrient samples were taken on a daily basis during most of this period.

As noted above, dosing is presently based on a float operated pump switch. During the 1976-77 studies a number of hydraulic loading rates were used; these are shown in Table 23. Operation during spring and early summer 1976 was limited by oxidation pond drawdown at the end of periods one and two. The third operation period was limited by a leak in the oxidation pond dike. Before the oxidation pond could be refilled unusually harsh winter conditions resulted in heavy ice formation and prevented flow from the pond. Suitable operating conditions did not occur again until March, 1977. Since that time, operation has been continuous, including the winter months.

Tracer studies were run during experimental operating periods. Results are given in Table 24 in terms of detention time.

Performance of Overland Flow System

Performance of the system during the experimental periods is indicative of overall performance. Removal and loading data are presented in Tables 25 through 28.

TABLE 23. 1976-1977 LOADING RATES OF CEDAR LANE TRAILER PARK OVERLAND FLOW SYSTEM

Period	Dates	No. of days	Application time hr/d	Application rate m^3/hr	Hydraulic loading rate cm/day
1	3/22/76- 4/21/76	31	12	4.1	8.18
2	6/3/76- 7/8/76	36	12	4.1	8.18
3	9/23/76- 10/13/76	21	9.25	4.1	6.31
4	3/16/77- 3/21/77	6	24	5.7	22.80
5	3/22/77-	21	24	2.8	11.36
6	4/12/77- 4/17/77	6	8	2.8	3.73
7	4/21/77- 5/12/77	4	4 hrs/wk	2.8	1.87 cm/wk

TABLE 24. DETENTION TIME AS A FUNCTION OF POSITION AND APPLICATION RATE

	Application rate, m^3/hr	
Distance, m	2-8	4.1
	Resulting Detention time, min.	
15	31	19
30	50	48
45	--	66
60	88	81

TABLE 25. BOD_5 REMOVAL IN CARBONDALE OVERLAND FLOW SYSTEM

Period	Hydraulic loading rate, $m^3/ha-d$	Influent BOD_5, mg/L	BOD loading rate, kg/ha-d	BOD, mg/L 30-m	60-m*	90-m**
1	818	27.4	22.1	19.7	12.1	10.8
2	818	18.0	14.7	5.9	2.7	2.8
3	631	69.6	43.9	12.4	5.0	--
4	2,280	43.6	99.4	17.0	13.3	13.7
5	1,136	20.2	23.0	16.7	5.0	4.9
6	373	9.2	3.4	7.0	4.5	3.7
7	27	15.0	0.4	11.5	--	--

* End of slope

** Nearly level area past end of slope

TABLE 26. SUSPENDED SOLIDS REMOVAL IN CARBONDALE OVERLAND FLOW SYSTEM

Period	Influent, mg/L	Loading rate, kg/ha-d	SS, mg/L 30-m	60-m*
1	22	18.0	--	--
2	24	19.6	--	12
3	35	22.1	12	40
4	34	77.5	20	30
5	24	27.3	10	13
7	26	0.7		

*End of slope

TABLE 27. PHOSPHORUS REMOVAL IN CARBONDALE OVERLAND FLOW SYSTEM

Period	Influent, mg/L	Phosphorus loading rate, kg/ha-d	P, mg/L 30-m	P, mg/L 60-m
1	3.25	2.66	1.17	0.48
2	1.78	1.46	0.61	0.21
3	3.44	2.17	1.81	0.32
4	5.05	11.51	2.77	2.31
5	3.34	3.79	2.56	1.70
6	2.50	0.93	1.88	1.30
7	3.00	0.09	2.50	1.80

TABLE 28. NITROGEN REMOVAL IN CARBONDALE OVERLAND FLOW SYSTEM

Period	Influent, mg/L	Nitrogen loading rate, kg/ha-d	NH_3-N, mg/L 30-m	NH_3-N, mg/L 60-m	NO_3-N, mg/L 30-m	NO_3-N, mg/L 60-m
1	4.5	3.7	2.9	1.0	2.3	0.5
2	8.0	6.5	2.6	0.7	0.4	0
3	31.6	19.9	9.9	0.4	3.5	0.6
4	29.1	66.4	21.6	20.3	1.1	0.7
5*	16.8	19.1	5.3	0.6	4.6	6.0
6	13.6	5.1	4.2	0.2	3.8	3.9
7	9.8	0.3	5.0	0.8	--	6.0

*Two distinct periods are reported, the better of which is reported here.

Actual loading of the system averaged approximately 38 m^3/d and 630 m^3/ha-d. This corresponds to 44 cm/wk or 6.3 cm/d, a very high loading rate in comparison to other sites. Operating period three in Tables 25 through 28 is a reasonable estimate of expected system performance.

Comparisons of BOD_5 removal with hydraulic and organic loading rates are shown on Figures 8 and 9. BOD_5 removal and hydraulic loading correlate well except for two points. Point #1 represents the first period of operation. The relatively poor performance could represent an inital period of system adaptation or buildup of humus to provide good treatment. Point #6 can not be explained. Because the effluent suspended solids concentration (Table 26) is greater than the influent suspended solids concentration in one instance, a source of solids must exist on the slope. The most likely source is humus (that collected prior to initiation of overland flow treatment) and/or erosion. Erosion does not seem likely because visible effects are not evident after 3 years of operation. Also, higher effluent suspended solids would have resulted with the higher loading rates if erosion was occurring.

Phosphorous removal performance was very good during 1976 and much less satisfactory during 1977. There could be a possibility of saturation of the system adsorption capacity for phosphorus. The soil mantle adsorbs phosphorus. Each

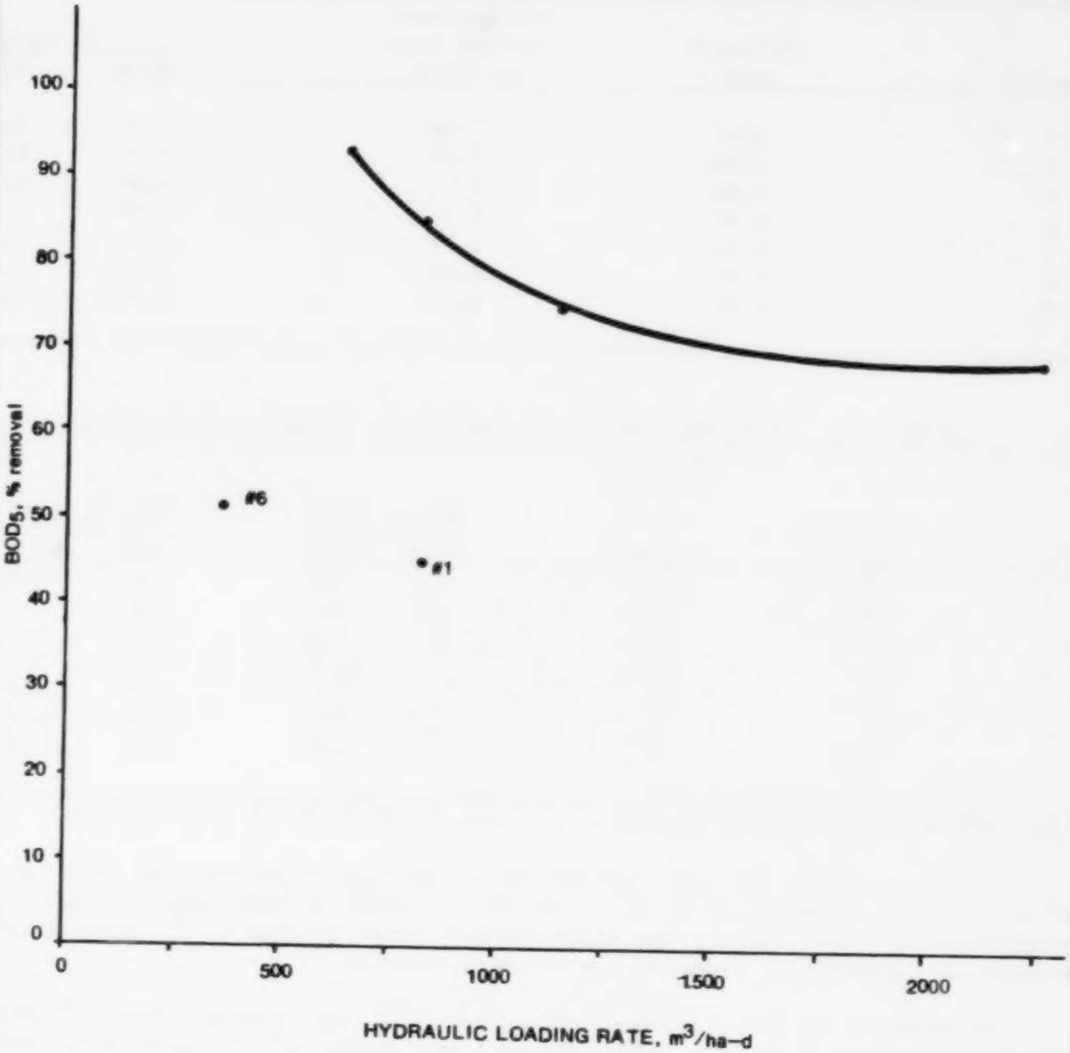


Figure 8. BOD_5 removal vs. hydraulic loading rate at Carbondale[7].

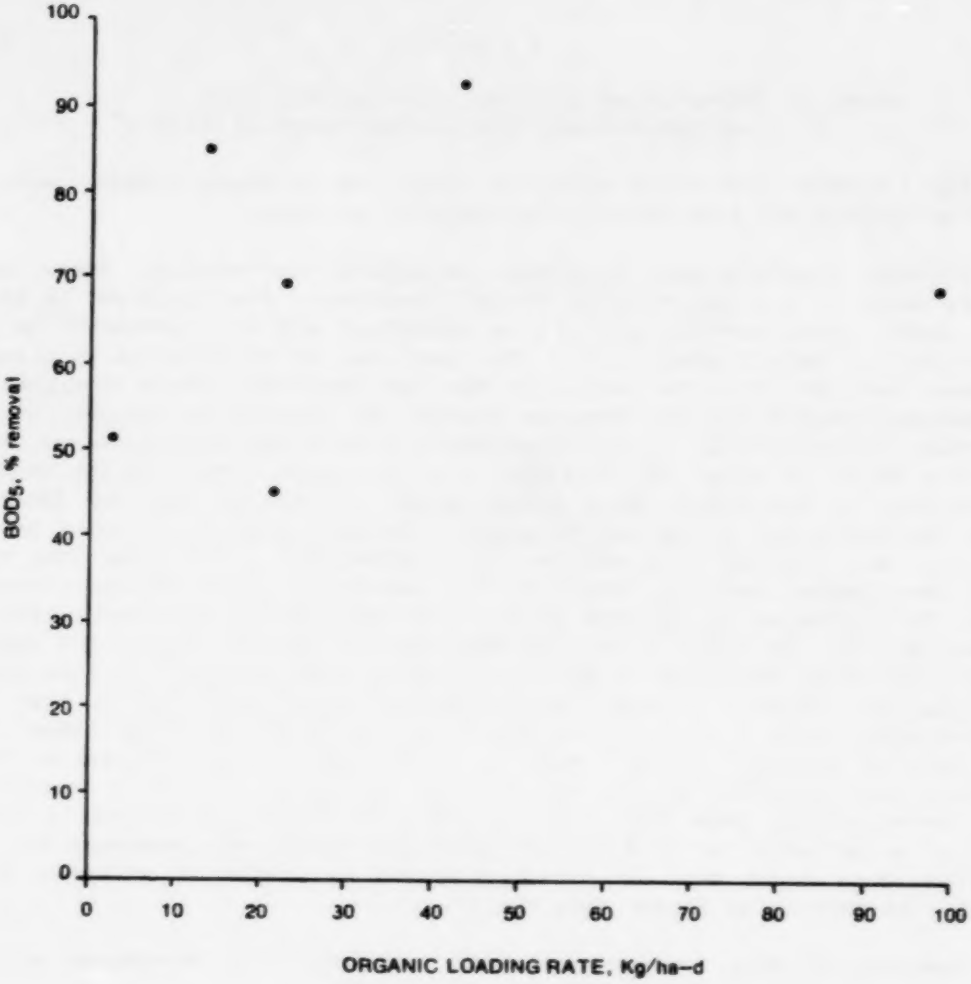


Figure 9. BOD_5 removal vs. organic loading rate at Carbondale[7].

soil has a limit which it can adsorb, or its adsorption capacity. Asaturian[7] performed a limited number of adsorption capacity experiments and estimated the capacity, x, to be given approximately by Equation (2)

$$x = 0.14\ c^* \qquad (2)$$

where x = Phosphorous sorption capacity gP/g soil
c^* = Equilibrium solution concentration of P, g/m^3

For a system with short detention times due to steep slopes, soil contact would be limited and true equilibrium would be unlikely.

Nitrogen removals were excellent throughout the studies. There are three primary modes of nitrogen removal by land treatment. Some nitrogen is removed by plant uptake. Some ammonia nitrogen is nitrified and thus converted to nitrate. The nitrate is then leached through the root zone or denitrified to nitrogen gas and goes into the air. The mechanism for nitrification (which requires oxygen) and denitrificaiton (which requires anoxic, or absence of oxygen, conditions) occurring simultaneously is not completely understood. Nitrification occurs in the thin sheet of water as it flows over the slope. The nitrate most likely accumulates in the humus. This accumulation is limited but the limit is not known. The humus may or may not be aerobic during operation. It will probably be anaerobic near the end of a wetting cycle. After drying for some time the layer would then become aerobic. While in the anaerobic state denitrification will result in conversion of nitrate to nitrogen gas. Since relatively little water leaches through the soil, losses to leachate are insignificant. The requirement of tall fescue is estimated to be 0.02 kg N/kg grass grown. At a flow rate of 38 m^3/d and an influent nitrogen concentration of 30 mg/L (which must be considered high), over 1 kg N will be placed on the system each day. Thus, the primary mode of nitrogen removal must be nitrification-denitrification. Excellent removals were recorded during experimental operating periods 1 through 4. The last three periods show much less removal. In operating periods 5 and 6 the decrease is probably due to a lack of anaerobic conditions necessary for denitrification. Some doubt must be directed toward the value of effluent NO_3-N for period 5 because it is larger than the 30-m value.

Removals of BOD_5, suspended solids, nitrogen, and phosphorus with detention time are shown in Figures 10, 11, 12, and 13.

Cost of System

Costs were not available for this system since the construction was minimal (provided by Southern Illinois University).

HANOVER, NEW HAMPSHIRE

Hanover, NH is the home of the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). Since May, 1977, CRREL staff have been investigating overland flow as a method of treating domestic wastewater. In the initial studies process performance was compared using tap water, primary effluent, and secondary effluent for application[9,10]. More recently the design relationships for treatment of primary effluent using overland flow techniques have been studied. The Hanover site characteristics are shown in Table 29.

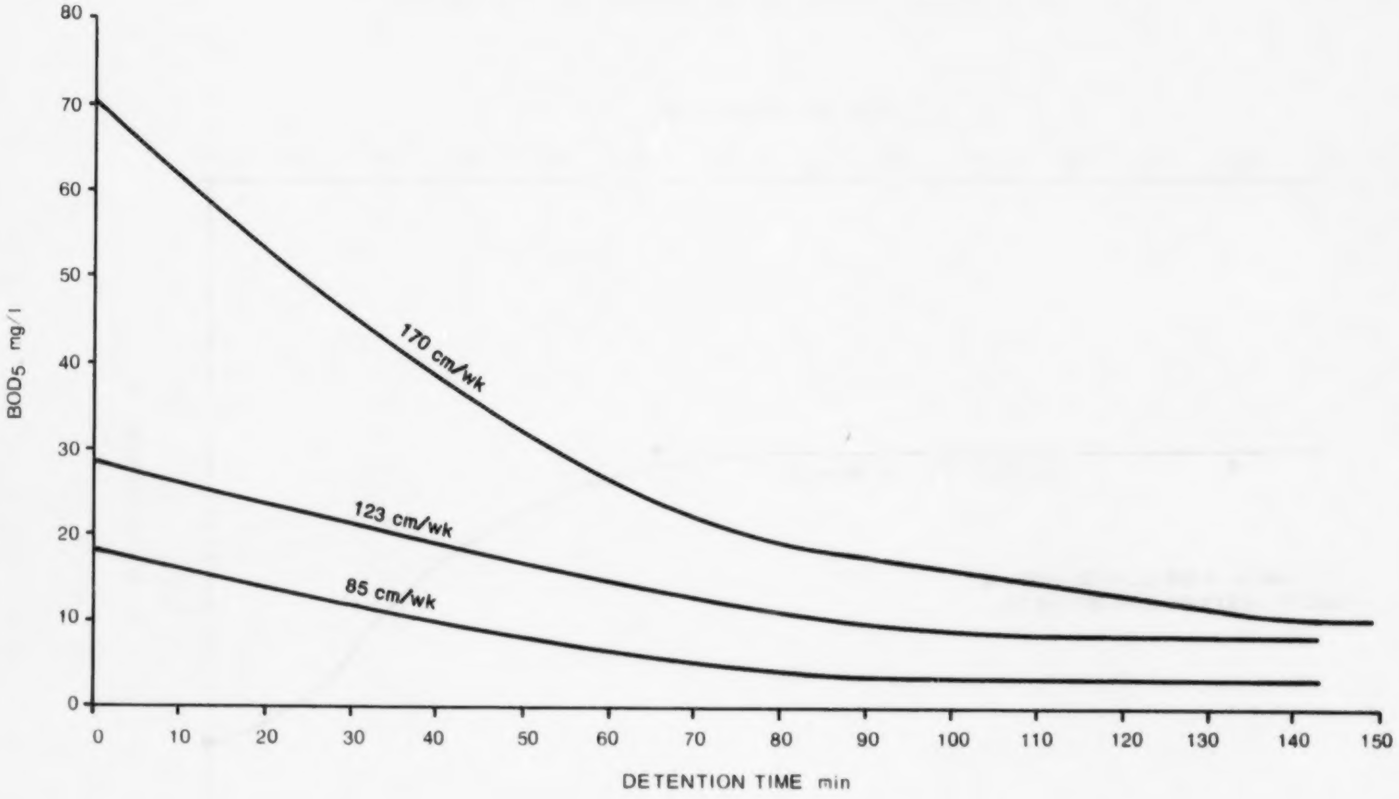


Figure 10. BOD_5 removal vs. detention time at Carbondale.

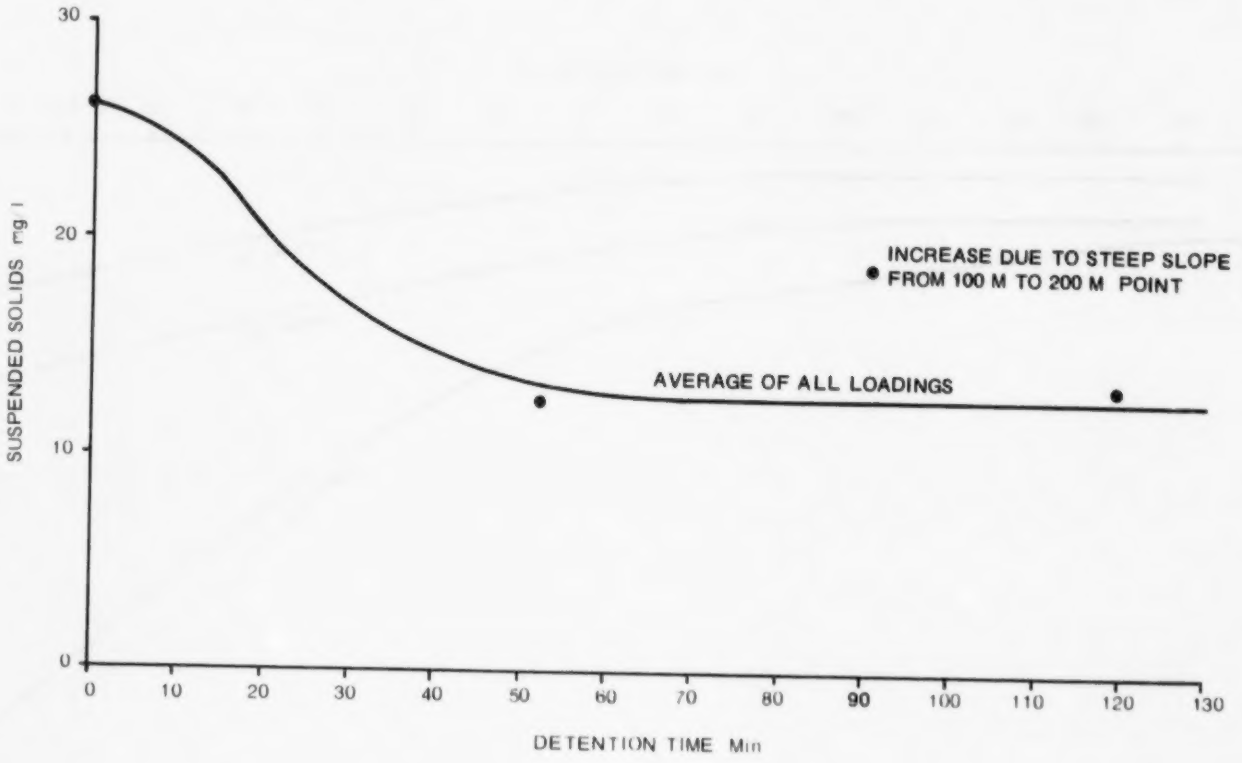


Figure 11. Suspended solids vs. detention time.

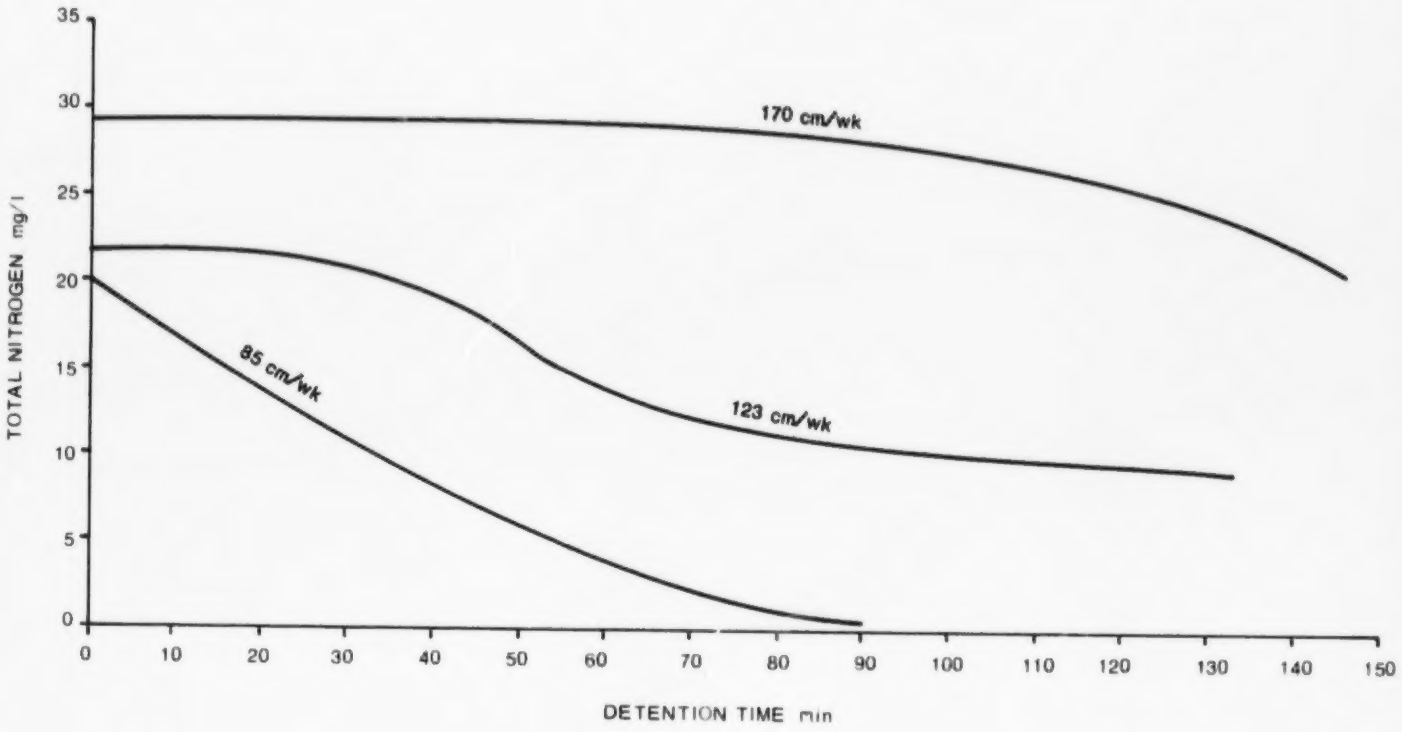


Figure 12. Total nitrogen removal vs. detention time.

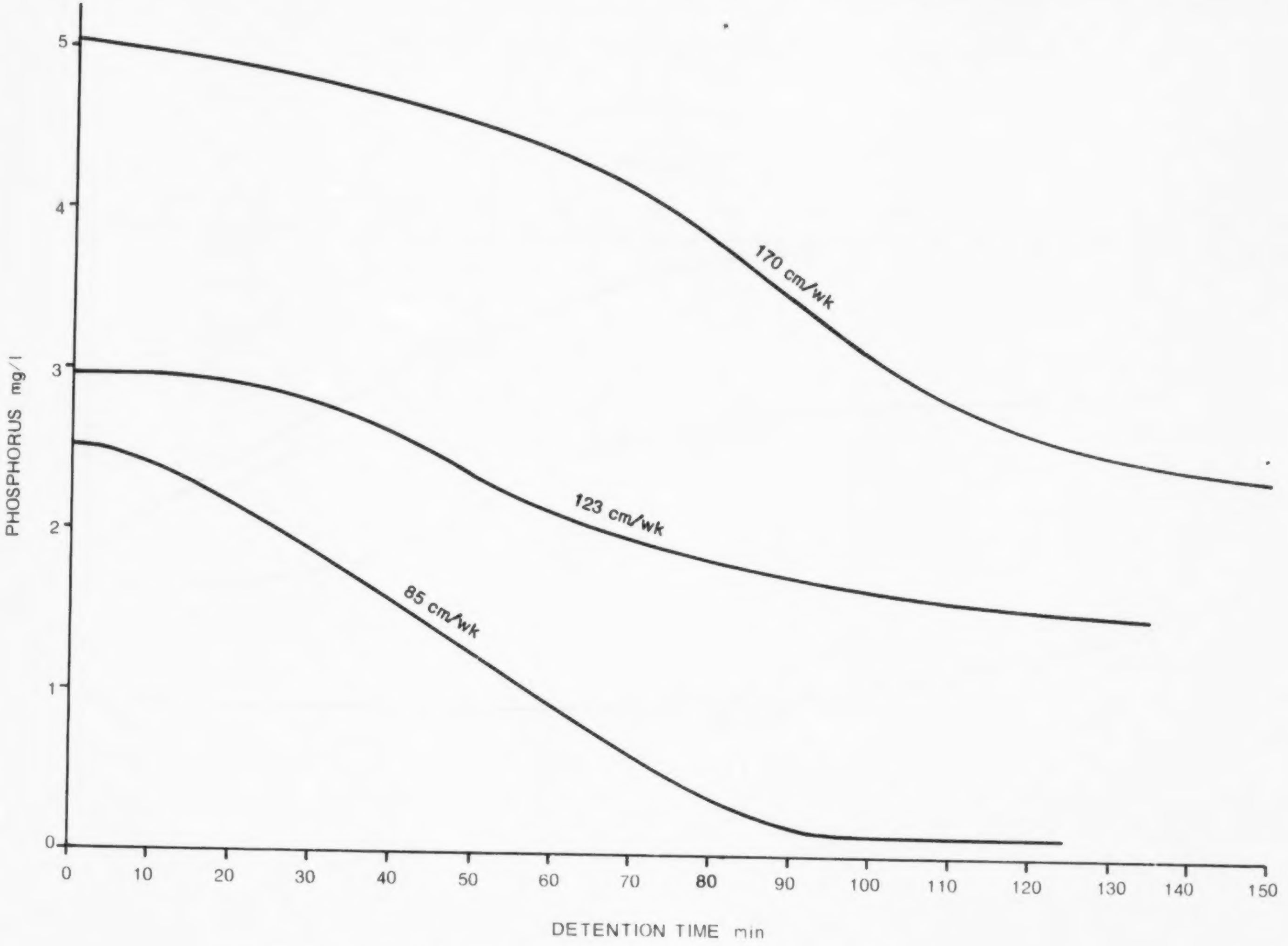


Figure 13. Phosphorus removal vs. detention time at Carbondale.

TABLE 29. HANOVER SITE CHARACTERISTICS

Type of wastewater - domestic sewage
Capacity - 2.1 m^3/d
Land area - .03 ha
Pretreatment - primary sedimentation or secondary treatment
Disinfection before application - none
Storage - 20 m^3
Soil type - Hartland silt loam (23 percent clay)
Application method - 3.8 cm PVC perforated pipe
Control methods - Manual
Crop - orchard grass, tall fescue, reed canary, perennial rye grass
Slope - 5 percent
Application rate - variable (5.8 - 47 cm/wk)
Application period - 7 hr/d
Yearly rainfall - 95 cm
snowfall - 185 cm
Temperature
Ave annual - 7°C
Days below 0°C - 160

The CRREL overland flow test facility consists of a three-cell site each 30.5-m long and having total area of 0.03 ha. The slope of the system is 5 percent. A schematic is shown on Figure 14. A rubber liner has been used to prevent percolation below 15 cm. Wastewater was supplied via a nearby domestic sewer and treated adjacent to the test cells. For the control cell, local tap water was used.

The principal purpose of studying overland flow at this location was to assess the effects of cold weather on the process and to develop design procedures based on parameters other than the hydraulic application rate.

The principal research activities on the CRREL overland flow project were terminated in the fall of 1979. A certain amount of information from the study has been reported[9], however, the major portion of the data analysis will not be completed until late 1980. The information on the initial studies conducted at CRREL on overland flow is summarized herein; that available from the more recent research is also presented.

Treatment Performance

First year performance information on the CRREL overland flow systems was obtained during the period from May, 1977 to April, 1978. As noted above, three sources of water were used on the plots. Tap water was taken from a local source and wastewater was drawn from a local sewer and given either primary or primary and secondary treatment by extended aeration on site. The quality of these three sources of water is given on Table 30. Note the relatively small difference between primary and secondary effluent.

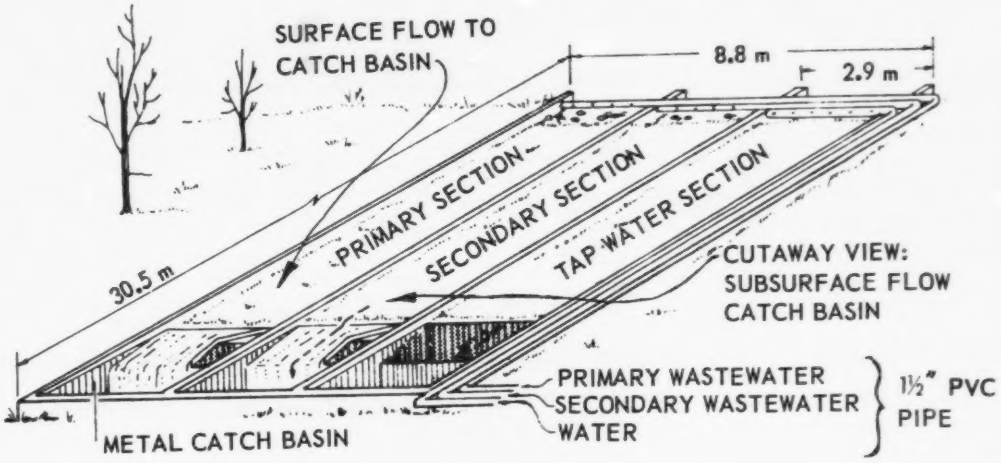

SURFACE FLOW TO CATCH BASIN
8.8 m
2.9 m
PRIMARY SECTION
SECONDARY SECTION
TAP WATER SECTION
30.5 m
CUTAWAY VIEW: SUBSURFACE FLOW CATCH BASIN
PRIMARY WASTEWATER
SECONDARY WASTEWATER
WATER
1½" PVC PIPE
METAL CATCH BASIN

Figure 14. Diagram of Hanover overland flow system (9).

TABLE 30. AVERAGE WASTEWATER QUALITY APPLIED TO CRREL OVERLAND FLOW SLOPES MAY 30, 1977 to APRIL 1, 1978

Parameter	Application concentrations		
	Tap	Primary	Secondary
Total nitrogen, N	0.3	36.6	33.5
Ammonia nitrogen as N mg/L	0.1	33.1	27.3
Nitrate nitrogen as N, mg/L	0.0	0.5	5.1
Total phosphorus, mg/L	0.6	6.3	5.9
BOD_5, mg/L	0.4	85.3	53.2
Total suspended solids, mg/L	1.4	74.6	30.2
Volatile suspended solids, mg/L	0.7	60.7	21.7
Cond, mhos/cm	91	524	519
pH, pH units	7.1	7.4	7.5
Fecal coliform, MPN/100 ml	0	7.9×10^4	1.8×10^4
Potassium mg/L	1.4	12.4	11.9

Source: Reference 10

Results of the study have been divided into warm and cold weather periods with average performance values from these periods given in Table 31. As is apparent from the data, a marked decrease in performance occurred during the cold weather. To determine the temperature below which treatment performance was unacceptable (BOD and SS greater than 30 mg/L each), the effluent BOD was correlated to the soil temperature. Optimum operating soil temperature was found to be about 14°C. The minimum soil temperature at which an effluent BOD of 30 mg/L with primary effluent could be achieved was 4°C. The 5 cm/wk loading rate is one of the lowest loading rates of the case histories reviewed.

A mathematical formula used to describe the runoff BOD vs soil temperature relationship is included with the graph of the data given on Figure 15. A similar relationship was established for estimating ammonia nitrogen in the runoff. The data presented in Figure 16 are for both primary and secondary effluent. At 4°C, the minimum temperature for acceptable effluent BOD, the ammonium concentration would be about 22 mg/L. The optimum performance would be about 17°C, 3° higher than for optimum BOD removal.

Nitrogen removals in the systems fed primary effluent were greater than in the system to which secondary effluent was applied. Neither wastewater was highly nitrified (despite the secondary treatment system being extended aeration). Considering the extent of removal during the summer months denitrifiers must have been active in both systems. Nitrification rates were greatly reduced during cold weather. The higher concentration of nitrate in the secondary effluent agrees with conclusions of other researchers. That is, the denitrification process is suppressed by the relatively high oxygen content in applied secondary effluent.

A surprising phenomenon of the cold weather operations was that even under a snowpack, the effluent irrigated plots remained green, while the tap water plot and surrounding vegetation were brown. The reasons for this have not been fully investigated; however, there was speculation that it could be related to the temperature of the effluent with the snow cover acting as insulation, or to the nutrient load provided by the wastewater. In either case adequate light transmission through the snow would be necessary.

TABLE 31. AVERAGE PERFORMANCE FROM CRREL OVERLAND FLOW SLOPES*

	Runoff concentrations				
	Warm weather May 30, 1977 to October 16, 1977			Cold weather December 12, 1977 to March 19, 1978	
Parameter	Tap	Primary	Secondary	Primary	Secondary
Total nitrogen, mg/L	0.7	5.4(94%)**	8.0(87%)	37.2(25%)	26.2(32%)
Ammonia nitrogen, as N, mg/L	0.1	3.2	2.6	24.3	21.5
Nitrate nitrogen as N, mg/L	0.1	1.6	5.2	2.0	3.8
Total phosphorus, mg/L	0.2	1.9(89%)	2.2(80%)	5.9	4.4(30%)
BOD^5, mg/L	1.4	11.2(91%)	4.6	65.3(59%)	13.9(80%
Total suspended solids, -mg/L	2.8	6.7(97%)	3.8(96%)	13.6(84%)	4.1(38%)
Volatile suspended solids, -mg/L	1.4	5.2	3.2	11.4	3.5
Cond mhos/cms	211	395	324	606	616
pH, pH pH units	7.9	7.7	7.6	7.2	7.3
Fecal Coliform, MPN #/100 ml	72	6.3×10^2	13	8.1×10^4	6.3×10^3

*Application rate of 5 cm/wk

**Numbers in parentheses refer to mass percent removal

Removal of bacteria is given in terms of fecal coliforms. The increase in fecal coliforms after treatment on the tap water plot indicates that this parameter is not a satisfactory measure of the sanitary quality of the runoff (as also concluded by the Utica researchers). Origin of the coliform bacteria is not necessarily human and a number of species are soil bacteria. Thus, the result is not surprising.

The conclusions drawn from the results of the first year of operation as presented in Reference 9 are:

- Wastewater application should cease whenever the soil temperature on the overland flow slope decreases to 4°C. The system should not be restarted until soil temperature increases to 4°C. Soil temperatures were taken at 2 cm below surface
- The effect of temperature on ammonium removal from overland flow systems is similar to that of conventional biological systems.
- Ammonium is more effectively removed in overland flow systems than nitrate. Nitrate is not immobilized and is carried into the runoff.
- Warm weather performance of the overland flow system was excellent. BOD_5 and suspended solids removals were greater than 90 percent.
- Fecal coliform concentrations in the runoff were found to be a poor measure of the sanitary quality of overland flow runoff (interference likely from soil bacteria).

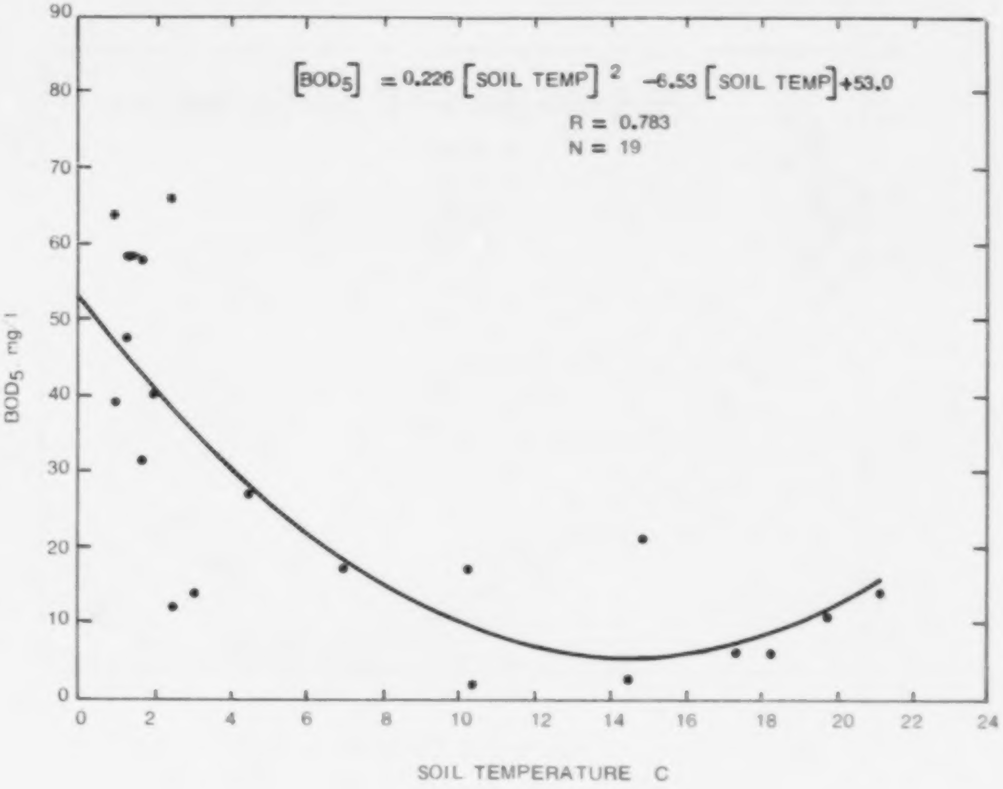


Figure 15. Average weekly runoff BOD concentration vs. soil temperature (primary section) at Hanover (9).

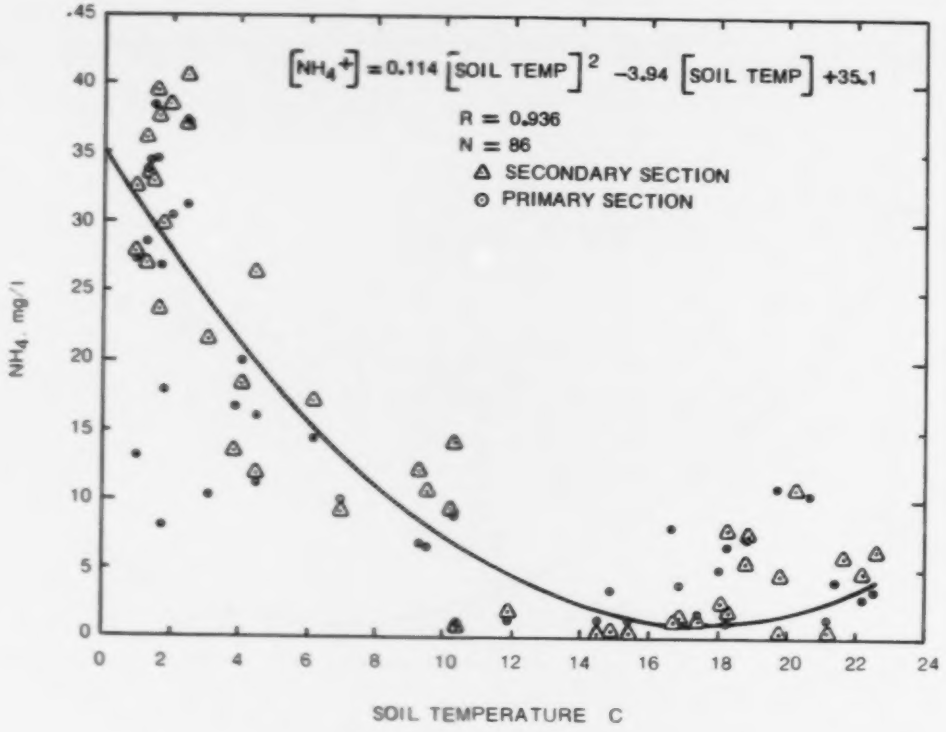


Figure 16. Average weekly runoff NH_4 concentration vs. soil temperature for primary and secondary sections at Hanover (9).

Design Methods

Ongoing research at CRREL has involved developing methods for designing overland flow systems. The results of this work are being presently analyzed; therefore, the available information is limited. This discussion is based on the preliminary findings; the major portion of the research will not be reported until late 1980.

In the past, the methods for designing overland flow systems have been based on hydraulic loading rates, which were not directly related to BOD or nitrogen removals[11]. Current efforts at CRREL are directed at developing a rational method for designing such systems. The basic design parameter being studied at CRREL is detention time. On the premise that if a given BOD removal can be related to the length of time waste remains on the treatment site, systems can be designed for treatment with any reasonable slope. Other factors such as climate, vegetation, and soil type must also be considered in design.

The preliminary results of data analysis are given on Figures 17, 18, and 19. The percent BOD and suspended solids removal have been plotted against the average detention time as shown on Figures 17 and 18. The design relationship is based on the plot of application rate vs. detention time shown on Figure 19. Data for this graph were obtained from WES as well as CRREL. The equation provides a proposed basis for rational design methods being developed for overland flow.

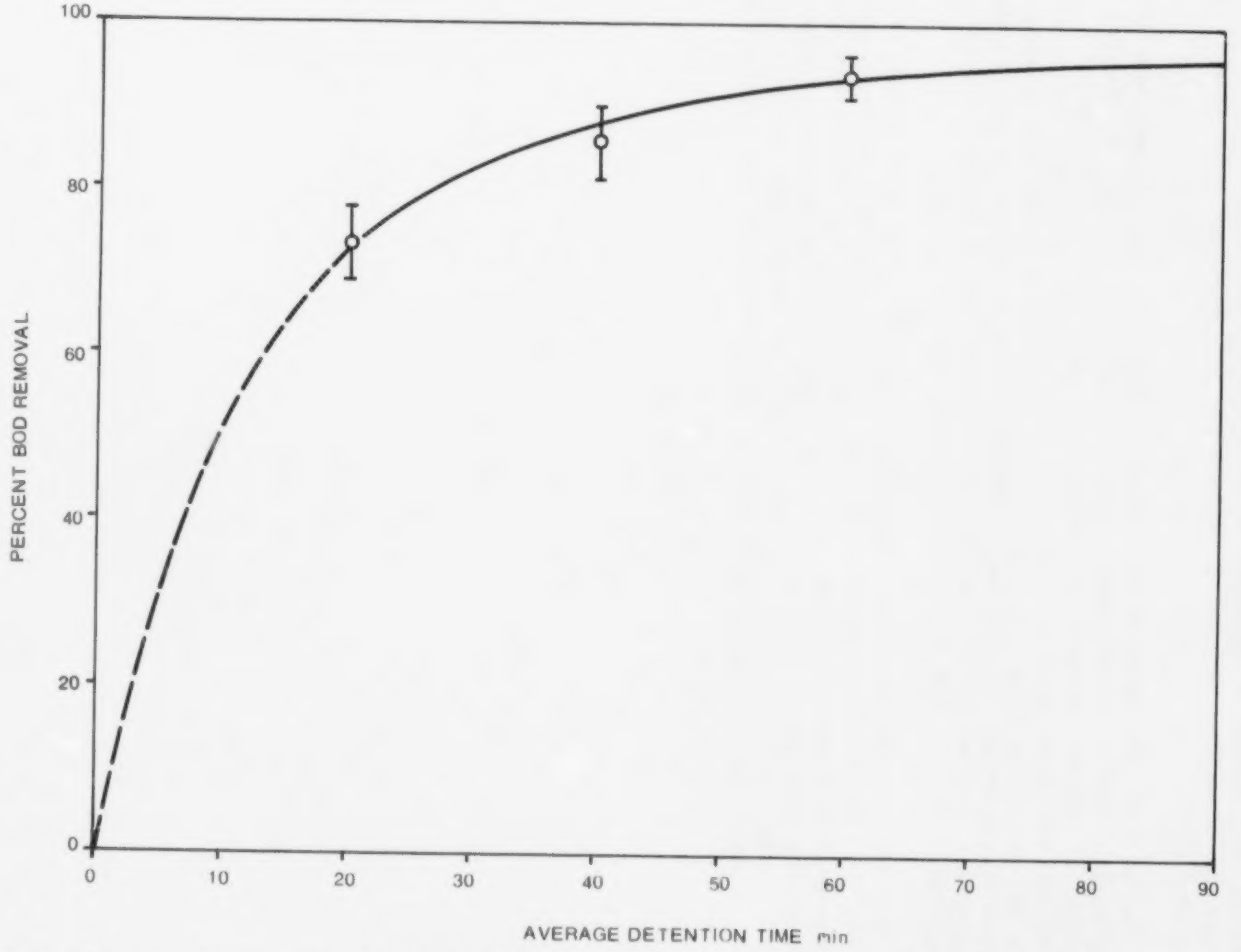


Figure 17. BOD removal vs. detention time for CRREL overland flow site receiving primary effluent.

Source: Unpublished data by Martel, C.J. et al to be presented in July 1980.

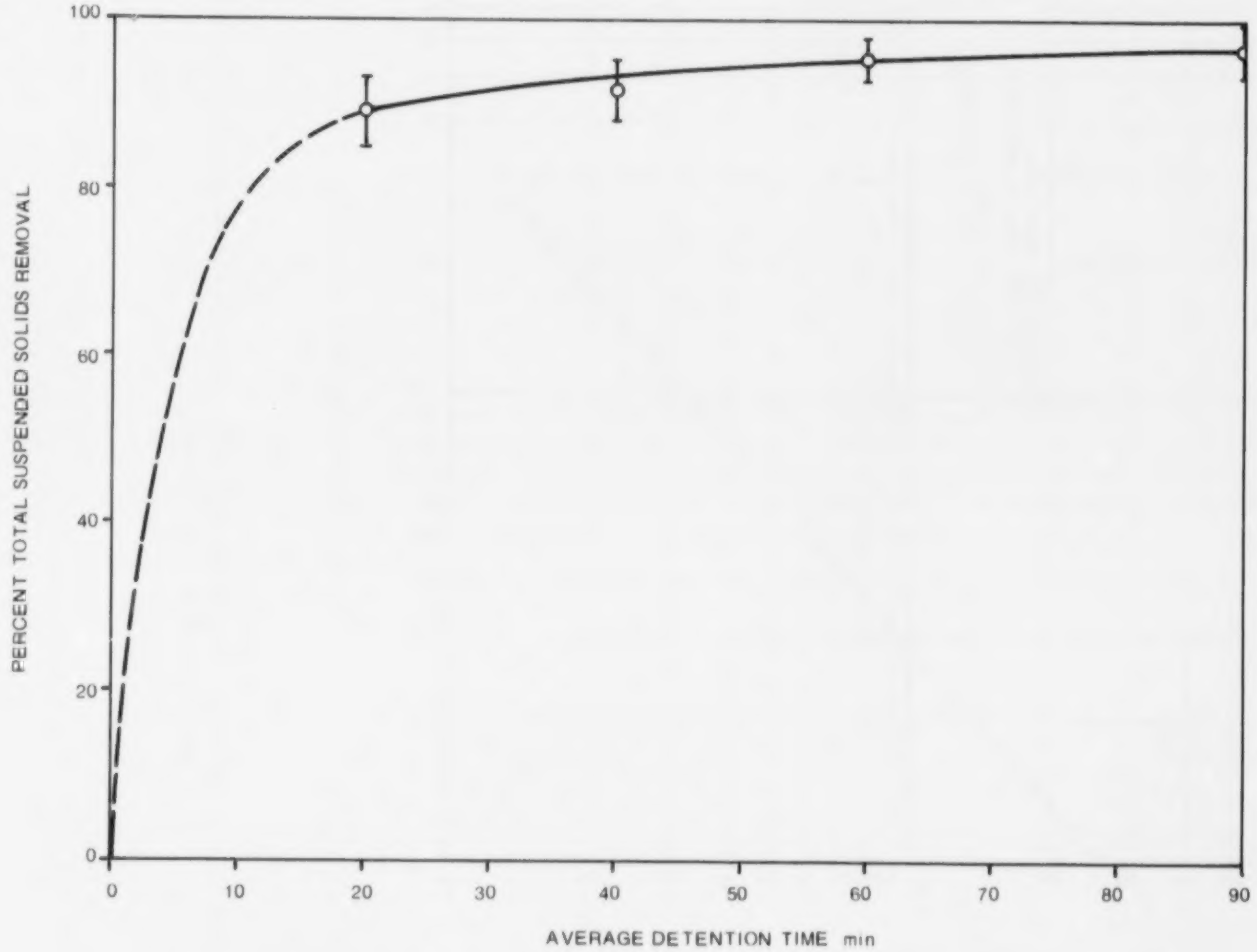


Figure 18. Suspended solids removal vs. detention time for CRREL overland flow site receiving primary effluent.

Source: Unpublished data by Martel, C.J. et al to be presented in July 1980.

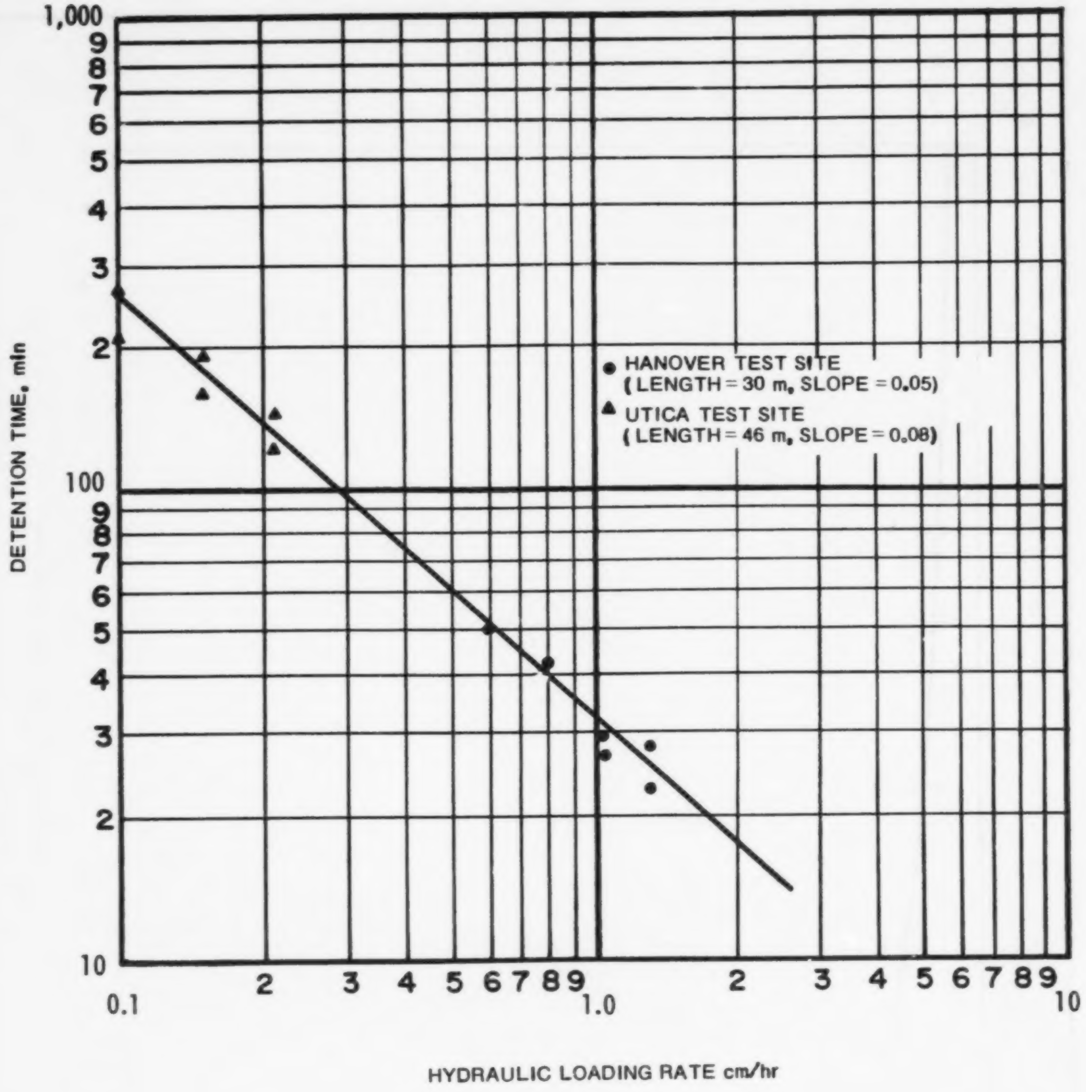


Figure 19. Relationship between hourly hydraulic loading and detention time at Hanover and Utica.

EASLEY, SOUTH CAROLINA

Easley, S.C. has a full-scale municipal overland flow system. This system provides for overland flow treatment of oxidation pond effluent and/or raw domestic wastewater. Site characteristics are described in Table 32. System performance data for the period January 4 to May 30, 1979, the first 4 1/2 months of operation, are summarized in Table 33. Raw sewage was applied at 11.8 cm/wk. Lagoon effluent hydraulic loadings ranged from 10.3 cm/wk to 19.3 cm/wk. BOD_5 and suspended solids removals are less than expected based on work conducted at other sites visited. Problems with establishing a good groundcover occurred due to drought which adversely affected performance during the period reported (The grass cover must be established by rainfall or irrigation prior to beginning overland flow operation). Algae removal has not met expectations of the operators, but improved grass cover in 1980 should result in improved performance.

TABLE 32. EASLEY SITE CHARACTERISTICS

Type of wastewater - domestic sewage
Capacities - 91 m^3/d
Land area - 2 ha
Pretreatment - screened and comminuted or oxidation ponds
Disinfection before application - none
Storage - 45 m^3
Soil type - red clay with small amounts of sand
Application method - low pressure fan nozzles
Control methods - hand operated gate valves and automatic solenoid valves and time clocks
Crop - predominately Kentucky 31 tall fescue
Slope - 6 percent
Application rate - 12-15 cm/wk
Application period - 6-8 hrs/d
Yearly rainfall - 117 cm
Temperature
Ave Max - 24°C
Ave Min - 12°C

TABLE 33. EASLEY, SC OVERLAND FLOW SYSTEM PERFORMANCE[15]

Parameter, mg/L	Raw sewage application		Lagoon effluent application	
	Raw sewage	Overland flow effluent	Lagoon effluent	Overland flow effluent
BOD_5	158	36	24	14
TOC (filtered)	28	23.8 (2 samples)	22	27
Suspended solids	161	54	57	42
Total phosphorus	4.7	3.7 (1 sample)	3.2 1964 and has been expanded	2.1
Orthophosphorus	5.0	3.9	2.3	1.7
NH_4	15.3	5.0	1.1	0.4

PARIS, TEXAS

Campbell's Soup owns and operates the largest overland flow facility in this country. This facility has been in operation since 1964 and has been expanded several times. Presently up to 35,000 m^3/d of cannery wastewater is applied year-round to 310 (360 gross) wetted hectares. Site characteristics are described in Table 34.

TABLE 34. CAMPBELL'S SOUP, PARIS, TEXAS SITE CHARACTERISTICS

Type of wastewater - industrial
Average flowrate, m^3/d - 17,000
Land area - 365 ha (gross), 285 ha (wetted)
Pretreatment - grease separation, coarse screening
Disinfection prior to application - none
Storage - none
Soil type - grey clay loam overlying red clay subsoil
Application method - sprinklers
Control methods - time clocks and pneumatically operated valves
Crop - predominantely reed canary
Slope - 2-8 percent
Ave application rate - 4.2 cm/wk (.84 cm/d, 5d/wk)
Application period - 6 hrs on 18 hrs off
Yearly rainfall - 114 cm

Pretreatment consists of grease separation and coarse screening by large rotary screens. After screening the water is pumped to the adjacent site and distributed through a network of pipes and sprinklers. Distribution is controlled by four time clocks, one for each raw wastewater pump. The time clocks signal the opening and closing of pneumatically operated valves at the head of each pipe lateral. Time clocks are set to operate laterals and sprinklers on a 6 hr on 18 hr off cycle. By this method flow is evenly distributed across the entire site.

Both the influent and effluent characteristics are monitored. Typically influent BOD ranges from 500 to 900 mg/L while effluent BOD ranges from 3 to 10 mg/L. Treatment performance for 1979 is summarized in Table 35.

TABLE 35. PERFORMANCE SUMMARY AT CAMPBELL'S SOUP, PARIS, TX

Month	Influent			Effluent			Percent removal (mass basis)	
	Ave flowrate $m^3/dx10^3$	Ave BOD_5 mg/L	Ave TSS mg/L	Ave flowrate $m^3/dx10^3$	Ave BOD mg/L	Ave TSS mg/L	BOD	TSS
Jan	14.5	935	284	14.4	10.6	20.7	98.9	92.8
Feb	20.1	1,270	609	18.6	13.1	23.0	99.0	96.5
March	18.3	835	413	15.0	5.8	56.2	99.4	88.8
April	18.3	1,010	1,126	14.0	7.5	35.3	99.4	97.4
May	19.5	330	214	14.4	4.7	54.9	98.9	81.0
June	17.4	525	236	12.3	5.8	39.9	99.2	88.0
July	14.2	930	602	12.5	4.3	58.5	99.6	91.4
August	16.2	574	370	13.8	3.3	27.7	99.5	93.6
Sept	15.9	790	506	15.4	5.0	27.6	99.4	94.7
Oct	18.0	227	354	17.0	4.0	17.4	98.3	95.4
Nov	17.6	323	516	17.4	5.0	25.4	98.5	95.1
Dec	16.5	-	-	14.2	6.5	21.7	-	-
Annual Ave	17.2	704	475	14.9	6.3	34.0	99.2	93.4

As shown, excellent results are obtained in both BOD and TSS removal. Two important factors that contribute to the high performance are the relatively low hydraulic loading, 4.2 cm/wk, and the highly degradable cannery waste. Results similar to those above would not be expected from overland flow treatment of domestic sewage even at lower loadings. Also shown above is that treatment performance is not effected by winter operation. Average minimum temperatures in winter range from -3°C to 10°C. Some reduction in system performance would be expected because of reduced bacterial activity, however performance during this period is essentially the same as for other times of the year. Research has shown that while individual bacterial metabolism is reduced the population of bacteria increases during the winter maintaining the same gross bacterial activity[16]. Because of this action wastewater application can be made year around and no storage is required.

The site was originally planted with a mixture of grasses including Reed Canary, red top, and tall fescue. It was expected that native grasses would eventually dominate, however the Reed Canary has become the predominate crop. Grass is harvested 1-2 times per year by contract with local farmers. Revenue from harvesting offsets operating costs by 5-8 percent. In the past grass was cut and then removed from the field while it was still green. It was then chopped and pelletized for cattle feed. Treatment was interrupted to allow the field to dry out enough to support equipment and to cut the hay. Future plans are for the grass to be cut, windrowed and allowed to dry on-site. Once dry the grass will also be baled and stacked on-site. The new procedure will take much longer than before and require portions of the field to be out of service longer.

Sprinklers are located about 25-m below the top of each sloped terrace to prevent the circular spray pattern from overlapping the terrace above. Slopes range from 100 m long at the older portions of the site to 50-m long at the newer portions. It was found after early investigations that the 50-m long slopes gave equivalent treatment. Slopes tend to follow natural contours and range from 1 to 12 percent.

Operation and maintenance problems have been minimal at Paris. Army worm infestation is a recurring problem but is controlled by spraying insecticide from the air. Mosquitoes have not been a problem. Originally many of the laterals were constructed from aluminum irrigation pipe; because of corrosion this pipe is gradually being replaced by buried PVC pipe. Buried butterfly valves were used in the older areas. Seating problems with these values led to the selection of totally enclosed diaphragm valves for newer areas. Butterfly valves that had to be exposed for repair and all the newer valves were placed in valve boxes for ready access.

Research Results

During 1968 a detailed research program was conducted at Paris[16]. The project included a coordinated study of climatological, agricultural, biological, hydrological, and chemical factors. At the time the site consisted of 197 ha of which 35 were isolated and studied. The conclusions of this report are summarized below.

- It was expected that a microclimate is created on the field due to evaporative cooling that makes conditions similar to northern climates. This was found not to be the case.
- Hay harvested from the site was found superior in quality and preferred by cattle over local grasses. Analyses showed high levels of nutrients.
- Bacteria found on the site are similar to typical soil microrganisms but are specific for the organic matter found in the wastewater.
- An increase in bacterial population during winter offsets a decrease in metabolic activity.
- Insecticides have no effect on microbial populations but are effective in controlling army worms and snails.
- 20 percent of the applied water is lost through percolation and 10 to 30 percent is lost by evapotranspiration. About 60 percent of applied wastewater runs off.
- The system is capable of consistently removing 99 percent of the applied BOD and up to 90 percent of the applied nitrogen and phosphorus.

- Little or no change in the organic content of the soil occurs.
- Vegetation, living and dead, provides the surface area for growth of bacteria.

Design Information

Campbell's Soups has compiled the following design information based on their work in Paris[16].

Length of slope	60-75 m
Slope	3-6 percent
Application period	8 hr on-16 hr off
Size of sprinkler nozzles	6.5 (50 L/min)-8 (80 L/min) mm
Distance between sprinklers	25 m
Hydraulic loading rate	4-9 cm/wk
Operating cost/m^3 effluent	\$0.041
Construction costs (1979)	\$1600-\$2500/ha (not including cost of land)
Operating pressure at sprinkler heads	340-480 K_{pa}
BOD applied	500-900 mg/L
BOD in effluent	10 mg/L

Costs

Construction costs per ha for the first 197 ha site built during 1960-1963 are given below[16].

Clearing and grading	\$ 894.00
Planting	267.00
Piping and sprinklers	860.00
Misc.	465.00
Total per ha	\$2,483.00

The above described overland flow systems descriptions and performance data are presented in Table 36.

TABLE 36. EXISTING OVERLAND FLOW SYSTEM DESCRIPTIONS AND DATA - SUMMER/WINTER

Location	Type of facility	Type of wastewater	Preapplication treatment	Runoff % of applied	Slope %	Slope length m	Wetted area ha	Ave. flow rate m^3/d	Hydraulic loading rate cm/wk	Organic loading rate kgBOD/ha-d	Nitrogen loading rate KgN/ha-d	Ave. percent removal			
												BOD	SS	N	P
Davis, CA	Research Pilot Studies	Domestic Sewage	Oxidation Pond	87	2	30	.05	15	20	16	**	70	69	**	**
Hunt Wesson* Davis, CA	Full Scale	Food Processing	Screening	21	2.5	30	97	12,000	9	166	8.1	97	99	84	-
Ada, OK†	Research	Domestic Sewage	Screening	47	2	36	2.4	510	10-20	61/68	13/12	98	98	90	50
			Primary	50	2	36	0.8	260	15-20	14/9	5/6	98	98	90	50
			Oxidation Pond	50	2	36	0.8	260	25-40	7.4/4.3	4.6/4.1	98	98	90	50
Utica, MS*	Research	Domestic Sewage	Oxidation Pond	-	2-8	46	0.50	46	6.5	2.2	2.0	55	57	90	50
								130	18	6.2	5.6	**	**	75	30
Carbondale, IL	Full Scale	Domestic Sewage	Oxidation Pond	83	7-12	60	0.06	38	44	26	13	76	**	64	64
Hanover, NH	Research	Domestic Sewage	Primary	25	5	30	.03	2.1	5	6.0	2.6	91/58	97/84	94/25	89/30
			Secondary	80						3.7	2.3	95/80	96/88	87/32	80/30
Easly, SC	Full Scale	Domestic Sewage	Screening	70	6	55	.53	91	12	32	3.7§	84	76	77	45
			Oxidation Pond	70		47	1.4	290	15	15	0.7§	59	48	74	52
Paris, TX	Full Scale	Food Processing	Screening, Grease Removal	87	2-8	60-75	285	17.2	4.2	42	.44	99	93	90	58

*Nitrogen added to promote grass or for research purposes.

†For spray application.

§NH_4 only.

**Not reported

SECTION III

PROCESS MECHANISMS

The overland flow process is a combination physical, biological, chemical process. Solids settling on the upper slope and filtration by the grasses throughout constitute the physical process which reduces the suspended solids. This process is affected by distribution method and type of grass cover. The distribution method will determine the solids concentration near the influent application point. Gravity application will result in solids concentrating near the openings. Spray systems provide dispersed solids.

The biological process is similar to a conventional trickling filter. A bacterial or biological growth occurs on the soil surface. This growth is similar to the zoogleal mass growing on trickling filter media. As such performance is affected by temperature changes and flow variations.

The chemical process is the interaction of the soil and applied wastewater. Phosphorus is adsorbed on soil until the adsorption capacity is reached. Soil type determines this value.

Beyond this, the processes are not well understood. Until ongoing research is completed, the actual kinetics of this system are unknown. Researchers referenced in Section II hypothesised formulae but have not proven them at locations other than their own.

Organics removal is being investigated at the University of California, Davis, CA. Preliminary results have been published showing factors which impact organic removal (as well as those which do not). However, process kinetics have not yet been developed.

Organic removal as affected by cold weather conditions has been studied at Hanover, N.H. (CRREL). A relationship was developed between soil temperature and organic removal capability. This relationship needs to be tested elsewhere.

Suspended solids removals have been consistently excellent at all sites and during all weather conditions. Most solids seem to be removed readily on the upper portions of the slope.

Nitrogen removals are reduced during cold weather. Minimization of pretreatment seems to enhance complete nitrogen removal (leave carbon source in to aid denitrification). This relationship has not been developed.

Impact on nitrogen removal due to temperature has been studied at Hanover with results presented in Section II of this report. These results should be verified elsewhere.

As discussed previously, phosphorus removals are generally limited to soil adsorptive capacity. Alum has been used successfully to aid in phosphorus removals. Removal of phosphorus by alum addition is well understood and easily predicted. If the process mechanisms for phosphorus removal were better understood, less alum addition might be possible.

Impacts of rainfall on performance has been reviewed at Paris, TX and Utica, MS. Results have shown increased suspended solids mass discharge due to washing off of vegetative debris from the site. Results also showed dissolved solids are diluted. At Paris, rainfall events of 6.25 cm or greater, reduced total dissolved solids concentration.

SECTION IV

DESIGN CONSIDERATIONS

Principal considerations in the design of overland flow treatment systems include preapplication treatment, storage needs, loading rates, distribution system type and the selection and maintenance of vegetation. System geometry is not important as long as slopes are in the two to eight percent range and lengths are of the order of 30 to 60-m. Loading rates chosen in combination with the distribution system design will constrain the choice of slope length to a large degree.

PREAPPLICATION TREATMENT

In discussing preapplication treatment, a separation must be made between preapplication treatment needed and the fact that many overland flow processes will be "add ons" to existing secondary treatment systems. For example, an overland flow system may be added to an existing pond system. Even though the overland flow process can effectively treat raw wastewater, the pond system may be used for economic reasons (slightly smaller overland flow area may result). Thus, the loading rate chosen will depend on the level existing or planned of preapplication treatment, however neither primary nor secondary treatment is necessary for the design of a successful overland flow treatment system.

Required preapplication treatment consists of those operations that will prevent damage and unsanitary or unsightly conditions, and improve in process performance. Of greatest concern are the removal of grit, sand, debris, rags and other large objects that could result in damage to pumps, plugging of the distribution system or deposits on the upper slope areas. Screening or comminution and degritting would prevent these problems and should be included in all cases. Where primary or secondary effluents (including oxidation ponds) are available additional pretreatment measures are not usually necessary. Existing disinfection systems may be maintained with chlorination carefully controlled to prevent grass damage. Normally, disinfection would be provided after overland flow for surface application.

The degree of preapplication treatment required prior to treatment depends on the type of distribution system. Bar screening or comminution and degritting will be satisfactory in most cases where distribution is by gated pipe, side delivery flume, perforated pipes having perforations greater than 1 cm and spray nozzles having diameters greater than 0.6 cm.

In some cases specialized preapplication treatment may be necessary. Examples would include municipal wastewaters containing grease from meat processing, fiber from pulp wastes, or systems subject to high storm water flows. Industrial discharges should be required to remove materials deleterious to the treatment process at the source, but this will not be feasible in all cases.

Climate conditions can affect treatment performance. Jenkins et al[9] recommended that process operation be suspended when soil temperatures are less than 4°C, and when precipitation rates exceeded 1.3 cm/d. The former recommendation is related to decreases in biochemical reaction rates (for both organic removal and nitrification) at low temperatures while the latter results from the possibility of both decreased process performance and erosion due to higher flows. Experience with treating cannery wastes treatment using the overland flow process has included operation at soil surface temperatures near freezing. Organic removals were not seriously affected[16]. Because most wastewaters are substantially above freezing in temperature overland flow processes can be expected to perform satisfactorily at ambient air temperatures well below freezing.

In general, information on climatic effects is very limited. Because both organic removal and nitrification are carried out by microorganisms on the soil surface, reaction rates should be sharply affected by temperature. Lack of sensitivity to temperature, as measured by nearly constant effluent BOD values, would result from overdesign. If populations and/or detention times are high enough temperature effects on reaction rates are masked. Very few field studies have incorporated measurements along the slope and the corresponding temperature information. Thus, limitations imposed by weather are not well understood.

The relationship between degree of pretreatment and hydraulic loading rate is critical in a cost analysis. If a higher degree of pretreatment can result in an increased hydraulic loading rate, then reduced land costs should be reviewed to see if the pretreatment cost is justified. In his literature review and analysis, Overcash concluded that overland flow treatment of secondary effluent did not produce significantly better effluent quality than overland flow treatment of raw sewage or primary effluent[17]. This conclusion was made on systems with varying hydraulic loading rates for treatment of both primary and secondary effluents. There was no substantial difference in results with different pretreatment levels and hydraulic loading rates. The most likely reason for this result is that the high oxygen transfer rates in overland flow systems are coupled to relatively low surface loading rates. Secondary effluents place little demand on the biological potential of the systems and a relatively small demand on the physical (solids removal) potential.

The EPA Manual recommends 6.4 to 15 cm/wk loadings for treating primary effluent and 15 to 40 cm/wk for treating secondary effluent[18]. Deemer recommends the following loading rates:[19]

Pretreatment Level	Loading Rate, cm/wk
Raw	6.3 to 15
Primary	10.0 to 20
Secondary	20.0 to 40

Hydraulic loading rates chosen for a particular application will vary within the ranges as a result of varying BOD and suspended solids concentrations, seasonal temperature variation and possible precipitation effects. Predictive relationships between performance and loading rate are being developed through work at CRREL, RSKERL and the University of California, Davis. Preliminary results obtained at Davis were that performance, as measured by soluble organic removal, decreased when the hydraulic loading rate was increased from 15 to 20 cm/wk. These results support the EPA manual recommendations of hydraulic loading rate, between 10 and 20 cm/wk. Variations in reductions of Nitrogen and BOD_5 with different hydraulic loading rates are shown in Figures 20 and 21.

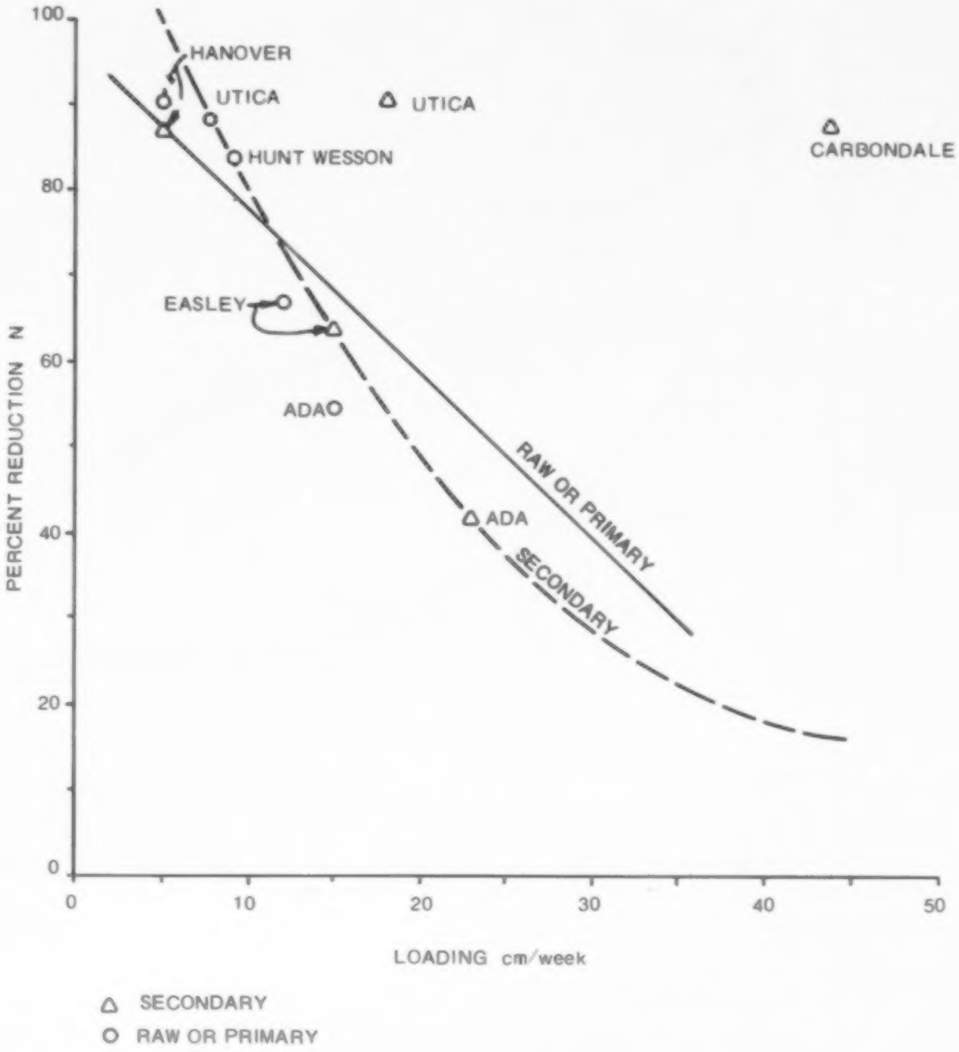


Figure 20. Hydraulic loading.

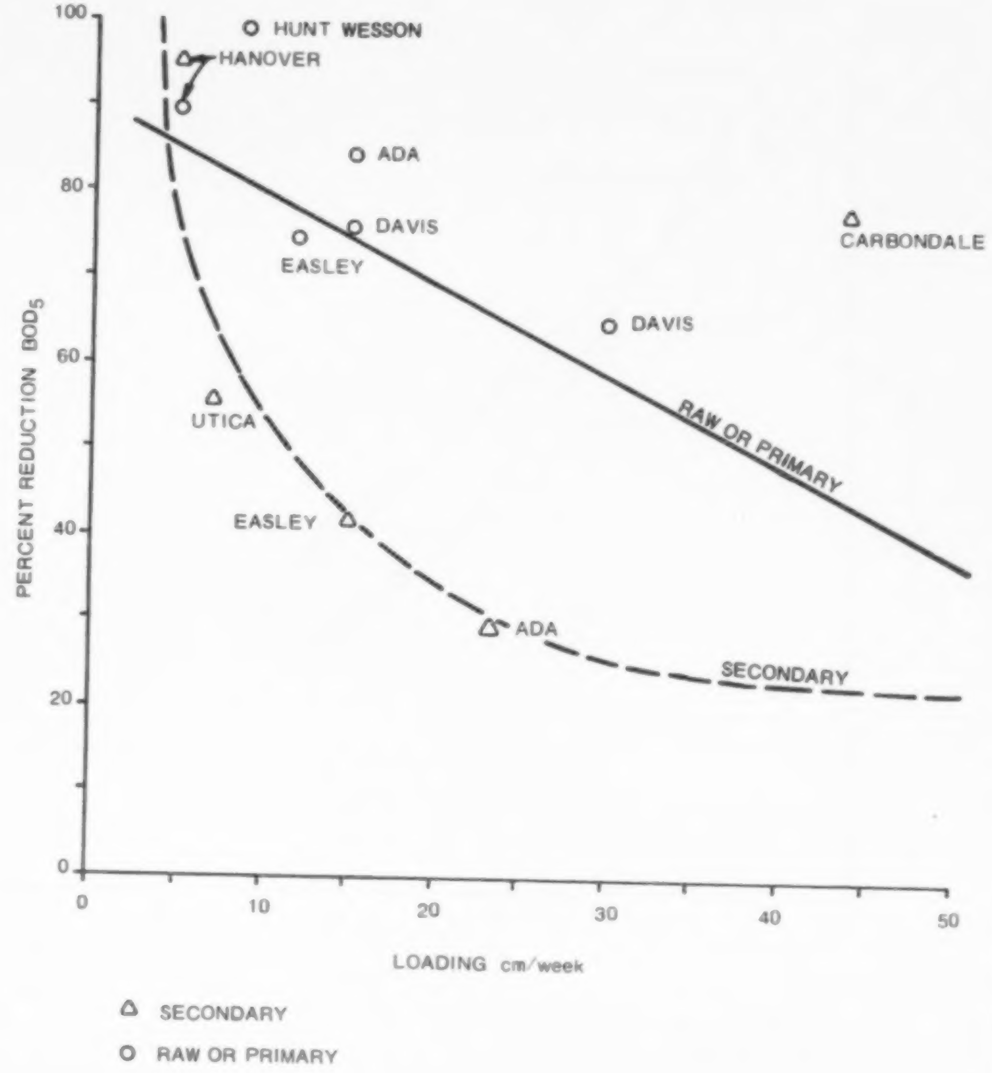


Figure 21. Hydraulic loading.

The variation of hydraulic loading rate with different levels of pretreatment effectively constrains the organic loading rate. Consideration of variations in wastewater strength results in relatively small variations in mass BOD loading rates (kg/d) over the entire range of hydraulic loading rates. Review of available information on overland flow process performance under various loading conditions supports the conclusion that organic loading rates are not a strong function of pretreatment.

Oxidation pond effluent characteristics impact overland flow treatment performance mainly through algal cell concentrations and possibly prevailing algal species. The conclusion reached in the Pauls Valley system study[12] was that overland flow treatment of pond effluent resulted in effluent suspended solids concentrations greater than 30 mg/L. Excellent suspended solid removals with overland flow treatment of pond effluent were obtained at Davis, CA., where terrace runoff suspended solids concentrations were consistently less than 30 mg/L. These differences appeared in spite of relatively similar hydraulic and solids loading rates and use of similar slopes (2 to 3 percent). The climates are also similar (note that problems occurred during summer operation but not during winter operation at Pauls Valley while the Davis pilot system was only operational in the winter). Differences in algal species or grass cover characteristics may have accounted for the differences in performance at the two installations. Algal species were not identified in either report. Grass cover at Davis was annual rye grass while the cover at Pauls Valley was a mixture of Kentucky 31 fescue, annual rye, and bermuda grass.

STORAGE NEEDS

Storage needs are based on two considerations: temperature effects and precipitation effects. BOD_5 removal and nitrification/denitrification rates are reduced during cold weather. Jenkins et al recommend overland flow systems not be operated when the soil temperature is below 4°C[9]. They found the optimum NH_4 removal to occur at a soil temperature of 17°C, and suggested the following equations for:

$$BOD_5 = 0.226\ (\text{Soil Temp})^2 - 6.53\ (\text{Soil Temp}) + 53 \qquad (3)$$

$$NH_4 = 0.114\ (\text{Soil Temp})^2 - 3.94\ (\text{Soil Temp}) + 35.1 \qquad (4)$$

BOD_5 = Remaining concentration in runoff
NH_4 = Remaining concentration in runoff

Soil temperature is at 2 cm below surface.

These equations have not been applied elsewhere. Variations due to other site chracteristics or climate are not known. The above formulae were developed using a hydraulic loading rate of 5 cm/wk. There was no apparent difference in the relationships when applying primary or secondary effluent.

Using design of effluent standard values for BOD_5 and NH_4 concentrations in equations (3) and (4) allows calculation of critical soil temperatures. Coupling the critical soil temperature with background data on soil temperatures and expected effects of the wastewater on soil temperature, the number of storage days can be determined.

Decreased organic removals during cold weather were reported in other studies[3,4,5], but those areas were not exposed to the extreme cold found in New Hampshire. The EPA Manual suggests use of winter rates (October 1 to April 30) one half those for the summer months (10 cm/wk and 20 cm/wk, respectively)[18]. Days are deducted for expected freezing conditions. This approach provides both a number of application days and modified application rates. Application area and storage needs are then derived from the compilation. The advantage of this approach is that a more accurate estimate of storage needs can be made than a gross approximation based on climatic data. General application of this approach, or any other requiring storage, should be reserved to regions with extremely low winter temperatures. Excessive differences in winter and summer area requirements can result in operating problems in arid regions where summary flows may not be enough to satisfactorily maintain vegetation. A second factor is that lowering winter application rates and storage will result in lowering applied wastewater temperature and therefore soil temperature will be lowered also.

Storage is also needed for days with heavy rainfall. The actual storage needs depends on the statement, presentation, and interpretation of discharge standards. Peters, et al[20], have studied the influence of storm runoff on overland flow treatment for nutrient removal. When failure occured maximum allowable N and P concentrations were not exceeded but maximum allowable mass effluent loads were. Deemer[19] reported similar experience for BOD_5 removals. He concluded that overland flow operation should not be halted during storm events and that storm runoff from an operating overland flow system was of the same quality as storm runoff from an adjacent nonoperating system. If the discharge standards are based on concentration only, then storage for storm events is unnecessary. If the discharge standard includes a maximum mass discharge rate, storage should be provided. BOD_5 mass discharge limits may be exceeded as the result of heavy precipitation even during nonoperating periods. Storage will lessen the possibility of partially treated effluent entering the receiving stream (partially treated due to high flow and corresponding low detention time).

In areas having long dry summers and high evapotranspiration rates, such as the southwestern United States, storage may also be necessary to provide enough water for summer irrigation requirements. Conventional irrigation would maintain the cover but not the bacterial population.

DISTRIBUTION SYSTEM

Wastewater can be distributed on the overland flow slope by sprinkling or by gravity flow from a pipe or trough. The results of the Pauls Valley project[12] showed little difference between distribution by sprinkler (2 types used) or by pipe with orifices. These results were found with treatment of both raw sewage and pond effluent. The spray system has the advantage of spreading solids and high strength organic wastewater over a larger area. This advantage is not apparent until the wastewater strength exceeds typical raw municipal wastewater BOD_5 and suspended solids levels (200-250 mg/L each). Cannery wastes with BOD_5 levels greater than 400-600 mg/L can kill the grass next to distribution pipe. The exact level where this becomes a problem is unknown at this time.

A comparison of spray and gated pipe distribution system is shown below:

System	Advantages	Disadvantages
Spray	1. Larger area for initial distribution of solids (avoids high initial concentrations) 2. Greater distribution of high strength wastes to prevent grass damage	1. Aerosol potential 2. Clogging nozzles unless fine screened (preapplication) 3. Pumping energy required to provide pressure
Gated pipe	1. Low pressure, minimal energy 2. No aerosols 3. No moving parts to maintain	1. Solids concentrations at pipe discharge

For treatment of domestic wastewater, at any preapplication level, gated pipe (or similar type of low pressure system) is preferred. This is due to low energy required, absence of aerosols, and ease of maintenance. Solids accumulation at the pipe can occur but the magnitude of this problem is such that maintenance required would be infrequent (e.g. annual).

Low pressure pipe systems of several types are available. The most common is gated pipe. Gated pipe is readily available from irrigation suppliers. Openings of 2.5 cm diameter or square are equally spaced along the pipeline. Other sizes are available. These openings have slides which can be adjusted to allow the desired flow out of the pipe. In lieu of gates bubbling orifices can be used. Some installations have utilized plastic pipe with openings cut in the pipe sidewall.

There are many options available for sprinkler systems. Piping may be buried or laid on the surface. Surface piping is usually aluminum tubing. Aluminum should not be buried. Plastic pipe has been preferred for buried systems (lower cost for plastic than other material). Surface systems are usually portable and can be moved if the operation is to be changed. Solids set systems lack flexibility in placement but are not in the way of field operations. Selection of the preferred option depends on preferences of the designer or operator and cost. While the solid set (buried) system is more costly for installation, the O&M cost is less than the movable system.

Selection of the type of sprinklers to use depends on designer or operator preference. Sprinklers can be chosen to provide fine or coarse spray, operate at pressures from 138 to 414 kPa and greater, and provide almost any application pattern. Techniques for sprinkler selection and sizing as well as lateral design can be found in (13) and (14), as well as in most major sprinkler manufacturers literature.

Distribution sytems must be designed to handle variation in wastewater flow and cyclic loading of benches. Controls can be manual or automatic. Control devices consist of electrically or pneumatically operated valves located in distribution laterals. Operation can be by on-off switch or by time clock. In larger systems with two or more constant speed pumps automatic controls must be designed to increase or decrease the number of laterals on line as a pump comes on or off. In this type of system separate time clocks controlling sets of laterals should be provided for each pump. No matter what the size of the system, flexibility should be built into the system to allow changes in spray programs. Pump capacity and operating pressures should be sufficient to take advantage of the entire site area but flexible enough to allow higher rates on partial areas without excessive pressures at individual sprinkler heads or gates.

Selection of the distribution systems also depends on the arrangement of the benches or terraces. Ideal locations have slopes of 2-8 percent occuring naturally. The benches then follow natural contours. There may be one continuous bench or several in series with collection uphill from the next bench. Runoff is collected and routed around lower benches. On level areas the benches may be placed such that one distribution lateral serves two benches. Similarly, one drainage ditch serves two benches. This type of layout is shown on Figure 3, the schematic for Davis, CA. The layout selection is based on economics of earth moving and pipeline layout.

SELECTION AND MAINTENANCE OF VEGETATION

Vegetation is a critical element in an overland flow system because it pro- growth, a mechanism for nutrient removal assimilation, and potential revenue to vides soil erosion protection, filtration, an environment for beneficial bacteria help defray operating cost. Selection of vegetation must include consideration of alternative plant species that will provide the benefits above as well as having a high water tolerance and be adaptable to the local climate. In some instances salt and/or metal tolerance may be necessary.

Grasses or forage crops are necessary to prevent erosion. Certain species that tend to grow in sparce clumps are not desirable since channeling could develop. Filtration of wastewater would be limited with grasses that bunch.

The most commonly used grass has been reed canary grass. Bermuda grass has also been popular, but is usually limited to warm climates because growth stops when soil temperature drops below 16°C. During dormant periods, plots can be overseeded with other grasses such as rye. The Werribee Farm System in Australia has had excellent success with Italian rye grass. Most often a variety of grasses should be planted and the most suitable species will eventually predominate. In some areas, this may be a native grass.

The forages that are adaptable to an overland flow system are not usually readily marketable. However, when grown under overland flow conditions nutrient contents are increased to a point where they are comparable to higher quality varieties[16]. The nutritive value of the forage depends on harvesting at the proper time.

Weeds and insects can be a problem. If slopes are less than 2 percent or grading was inadequate, mosquito breeding may occur in standing water. Other types of insects associated with the particular crop (e.g. cutworm) are agriculture-related and must be controlled by pesticides. Weeds are not a problem unless they interfere with marketing the crop. A large percentage of weeds can degrade crop quality or cause rejection of the harvest. From a treatment point of view, the weeds are not likely to cause a problem.

It is important to remember that the grass is of primary concern as a treatment media and secondarily as a crop. Grass growth should be developed to increase treatment performance and not for maximum yields. For example, the bacteria required for treatment of wastewater needs a dense mat of vegetative matter in the line of the wastewater flow. If grasses are allowed to grow too high they may shade out lower species and create bare patches close to the soil thereby effecting treatment performance and creating potential for erosion.

Overland flow slopes attract birds to an extent. High grass provides a habitat from small mammals and the moist soil provides excellent conditions for insect breeding. Hawks and similar birds are attracted because of the concentrations of prey.

PERFORMANCE AND RELIABILITY

Overland flow performance results from systems reviewed were presented in Table 36. Secondary treatment requirements for both BOD and suspended solids effluent concentrations are consistently met or exceeded. Nitrogen removals are excellent during warm weather. Phosphorus removals are marginal except when alum is added.

The reliability of overland flow systems appear to compare favorably with other secondary and AWT systems, but more data are required. This is especially critical in cold climates and where systems may be subject to high intensity storms.

DISCUSSION

Experience with overland flow systems has been limited. With the exception of the Werribee, Australia and the cannery waste treatment systems, there are no long-term, full-scale systems in operation. Considerable pilot scale work has been accomplished at the Ada, OK; Hanover, NH; Carbondale, IL; and Utica, MS sites. The most recent results of experiments at these sites have not been published at this time. Pilot and full scale research work is underway at Davis, CA. Preliminary data have been reported in full-scale systems at Pauls Valley, OK and Easley, SC. Information from these varied sources is difficult to compare. Climates are different and results are reported in different forms. The actual mechanism of treatment by overland flow is not completely understood but is apparently similar to an attached growth biological treatment system. Design equations modeled after trickling filter analyses will be developed in the future (Davis, CA).

As with other biological systems, cold temperatures reduce BOD_5 and nitrogen removal efficiencies. Work at Hanover, NH has confirmed this and has resulted in equations predicting removal efficiencies based on soil temperature. Cold weather impacts have been reviewed at Ada, OK. The limitation here has been the lack of severe winter temperatures.

There are several areas where all results are similar. Overland flow systems consistently produce effluent qualities better than secondary, in terms of BOD_5 and suspended solids. This applies to overland flow treatment of both raw sewage and primary effluent. Nitrogen removal is excellent during summer months with deterioration during cold weather (below freezing or ground temperatures below 4°C). Phosphorus removal is limited unless enhanced by adding alum.

Loading rates have been expressed in several ways. The most commonly reported measure is the hydraulic loading rate. Organic loading rates have not been reported as frequently but do impact results. The rate at which results are impacted has not been determined. Application rates, frequencies, and durations are rarely reported but impact performance also.

Based on the success of overland flow treatment with high-strength cannery wastewater and raw municipal sewage, pre-application treatment should be minimized, depending on land costs and the cost of pre-application treatment tradeoffs. In general, more land is required for higher strength wastewater. If pre-application treatment (beyond screening and grit removal) is provided, then less land is required. The more preapplication treatment provided, the less land required. Based on the information gained through this report, there is inadequate knowledge concerning the specific point where land areas should be increased due to high strength wastewater. Work quoted showed successful operation at various loadings but there have been no demonstrated systems loaded to failure so the maximum is unknown.

SECTION V

DESIGN EXAMPLES

Three examples were developed to highlight the importance of climate on design. The design flow and sewage strength is the same for each case. Example one is typical of an arid, western location in the United States. Example two is typical of the northeastern United States where harsh winters can be expected. In both of the first two examples raw domestic wastewater is treated for the removal of BOD_5 and suspended solids. Example three represents the southern part of the United States where large amounts of rainfall occur. In this example oxidation pond effluent is treated by overland flow to remove nitrogen. Site characteristics for each example are given in Table 37.

TABLE 37. SITE CHARACTERISTICS - DESIGN EXAMPLES

Parameter	1	2	3
Location in U.S.	West	Northeast	Southeast
Type of wastewater	Domestic Sewage	Domestic Sewage	Domestic Sewage
Preapplication treatment	Screening	Screening	Oxidation pond
Raw Sewage [illegible]acteristics			
Flow			
Ave - m^3/d	10,000	10,000	10,000
Peak - m^3/d	30,000	30,000	30,000
Ave BOD_5 - mg/L	250	250	250
Ave SS - mg/L	250	250	250
Ave Total N - mg/L	50	50	50
Discharge Requirements			
Mo Ave BOD_5 - mg/L	30	30	15
SS - mg/L	30	30	15
Total N - mg/L	-	-	10
Climate			
Rainfall, cm/yr	25	100	145
Evapotranspiration, cm/yr	125	79	45
No. Days Ave temp $\leq$4°C	0	100	30
Soils	clay	clay	clay

Design Example 1 - Western United States

In this example the required discharge standard is 30 mg/L BOD_5 and 30 mg/L suspended solids and 85 percent removal efficiency. Design criteria was developed from information given in this report and is listed in Table 38.

TABLE 38. DESIGN CRITERIA - EXAMPLE 1

Hydraulic loading, cm/wk -	15
Application period, hr/d -	6-8
Application frequency - days on/days off	5/2
Expected BOD_5 removal (mass basis), percent -	92
Expected SS removal (mass basis), percent -	95
Slope, percent -	2
Slope, length, m -	40

Land Area--

Land area is determined as follows:

$$A = \frac{3.65\ Q}{H} \qquad (5)$$

A = Wetted land area, ha

Q = Design flow rate, m^3/d

H = Hydraulic loading, cm/yr

H = 15 cm/wk x 52 wk/yr = 780 cm/yr

$$A = \frac{(3.65) \times (10{,}000)}{780} = 47 \text{ ha}$$

Additional land area will be required if plans call for dewatering slopes before grass mowing and if grass will be dryed and baled on the field. The extra land required depends on the frequency of grass harvesting. For this example 30 days is allowed for two cuttings a year. Land area is increased by 30/365 or 8.2 percent.

Adjusted Wetted area = 1.08(47) = 51 ha
Allow 10 percent for ditches and roads
1.10(51) = 56 ha

Depending on local ordinances and the type of distribution device, a buffer zone encircling the site may also be required. Actual land area will be dependent on the site geometry.

Buffer zone - 50-m; assume application area is square.
4 x 56 ha x 10,000 m^2/ha x 50-m - 150,000 m^2 or 15 ha (6)
Total land required = 56 + 15 = 71 ha

Water Balance--

A water balance to determine runoff volumes is necessary for accurate sizing of collection ditches, catch basins and pumps and to estimate effluent wastewater strength.

$$P + H = ET + W_p + R \qquad (7)$$

P = precipitation, cm
H = hydraulic loading, cm
ET = evapotranspiration, cm
W_p = percolating water, cm
R = runoff, cm

Precipitation data can be obtained locally or from reference 23. Several methods are available for calculating evapotranspiration and are given in references 13, 14, and 24. Precipitation and evapotranspiration for grasses for example 1 are given in Table 39 and are typical of the western United States. Percolation is best determined by field testing (see ref 25). Calculated runoff is also given in Table 39.

TABLE 39. DESIGN EXAMPLE 1 - WATER BALANCE 1

Month	P Precipitation cm	H Hydraulic Loading cm	ET Evapotranspiration cm	W_p Percolation cm	R Runoff cm	R Runoff $m^3 x 10^3$	R Runoff % of H
Jan	4.80	65*	3.04	5	61.8	290	95
Feb	4.47	65	5.47	5	59.0	277	91
Mar	4.34	65	6.08	5	58.3	274	90
Apr	2.39	65	8.51	5	53.9	253	83
May	1.02	65	15.2	5	45.8	215	71
June	0.18	65	20.5	5	39.7	187	62
July	0.03	65	21.3	5	38.7	182	60
Aug	0.03	65	16.7	5	43.3	204	67
Sept	0.43	65	10.6	5	49.8	234	77
Oct	1.17	65	6.51	5	52.7	248	82
Nov	1.96	65	6.08	5	55.9	263	87
Dec	4.00	65	3.04	5	61.0	287	94
Totals	24.80	780	125	60	620	2,910	80

* 65 cm/mo = 15 cm/wk

Runoff volumes shown in Table 39 as m^3/mo were calculated as the product of land area and runoff given in cm/mo.

Effluent Characteristics--

The effluent BOD_5 concentration is dependent on the runoff volume and is calculated as follows:

$$BOD_5 \text{ applied}, \frac{kg}{mo} = \frac{\text{Hydraulic Loading}\left(\frac{m^3}{mo}\right) \times \text{Influent } BOD_5 \text{ Conc.}\left(\frac{mg}{L}\right)}{1000 \text{ mg/L/Kg/M}^3} \tag{8}$$

$$BOD_5 \text{ remaining}, \frac{kg}{mo} = BOD_5 \text{ applied}, \frac{kg}{mo}\left(1 - \frac{\text{Percent Removal}}{100}\right) \tag{9}$$

$$\text{Effluent } BOD_5 \text{ conc, mg/L} = \frac{BOD_5 \text{ remaining}, \left(\frac{kg}{mo}\right) \times 1000 \text{ mg/L/Kg/m}^3}{\text{Runoff}\left(m^3/mo\right)} \tag{10}$$

Effluent BOD_5 concentrations for Design example 1 at 92 percent removal are given in Table 40.

TABLE 40. DESIGN EXAMPLE 1 - BOD_5 REMOVAL 1

Month	BOD_5 applied		BOD_5 remaining	Effluent Conc.
	kg x 10^3	kg/ha	kg x 10^3	mg/L
Jan	76	1,620*	6.1	21
Feb	76	1,620	6.1	22
Mar	76	1,620	6.1	22
Apr	76	1,620	6.1	24
May	76	1,620	6.1	28
June	76	1,620	6.1	33
July	76	1,620	6.1	34
Aug	76	1,620	6.1	31
Sept	76	1,620	6.1	26
Oct	76	1,620	6.1	25
Nov	76	1,620	6.1	23
Dec	76	1,620	6.1	21

* Equivalent to 53 kg/ha·d

In this example the discharge requirement of 30 mg/L is not met during the dry months of June, July and August. The mass BOD_5 removed has not decreased from 92%. However, the runoff volume is substantially less than the volume of wastewater applied, so the remaining BOD_5 strength is concentrated. Based on existing information exact BOD_5 removal percentages can't be accurately predicted with slight changes in hydraulic loading rate. Based on information acquired by Thomas et al[4], dry periods between loadings result in poorer BOD_5 removal. The theory presented was that BOD_5 removal suffered due to the drying of microorganisms on the soil surface. This theory was proven by the researchers but at this time an accurate design prediction is not possible. If the overland flow system is likened to a trickling filter, an increased hydraulic loading should result in a decreased BOD_5 removal rate. The impact of combining these two effects is unknown. For illustrative purposes with this example, assume an increase in hydraulic loading from 15 cm/wk to 20 cm/wk at this location still results in a BOD_5 removal rate of 92%. The BOD_5 removal rates are purely assumptions developed for this example. Using the same procedures outlined above this changed assumption results in the following Water Balance and BOD_5 Removal as shown in Table 41 and Table 42.

This second set of values for example one (Table 41) shows the impact of increasing runoff in meeting a discharge concentration. The designer must consider the concentrating effects of arid climates. He must also provide an operating plan that insures minimum drying of slopes. For example, operate 6 days on/1 day off instead of 5 on/2 off.

Design Example 2 - Northeastern United States

In this example cold weather with mean air temperatures of less than 0°C are experienced for 140 days with corresponding soil temperatures of 4°C experienced for 100 days. There is no correlation for air temperature related to soil temperatures. The soil temperature is a function of snow cover depth and duration. The

TABLE 41. DESIGN EXAMPLE 1 - WATER BALANCE 2

Month	P Precipitation cm	H Hydraulic loading, cm	ET Evapotranspiration cm	WP Percolation cm	R Runoff cm	R Runoff $m^3 \times 10^3$	R Runoff % of H
Jan	4.80	87	3.04	5	83.8	394	96
Feb	4.47	87	5.47	5	81.0	381	93
Mar	4.34	87	6.08	5	80.3	377	92
Apr	2.39	87	8.51	5	75.9	357	87
May	1.02	87	15.2	5	67.8	319	78
June	0.18	87	20.5	5	61.7	290	71
July	0.03	87	21.3	5	60.7	285	70
Aug	0.03	87	16.7	5	65.3	307	75
Sept	0.43	87	10.6	5	71.8	337	82
Oct	1.17	87	8.51	5	74.7	351	86
Nov	1.96	87	6.08	5	77.9	366	90
Dec	4.00	87	3.04	5	83.0	390	95
Total	24.80	1044	125	60	883.9	4154	85

TABLE 42. DESIGN EXAMPLE 1 - BOD_5 REMOVAL 2

Month	BOD_5 applied Kg x 10^3	BOD_5 applied Kg/ha	BOD_5 Kg x 10^3	Effluent Conc. mg/L
Jan	101	2160	8.1	20
Feb	101	2160	8.1	21
Mar	101	2160	8.1	21
Apr	101	2160	8.1	23
May	101	2160	8.1	25
June	101	2160	8.1	28
July	101	2160	8.1	28
Aug	101	2160	8.1	26
Sept	101	2160	8.1	24
Oct	101	2160	8.1	23
Nov	101	2160	8.1	22
Dec	101	2160	8.1	21

soil temperature is taken at 2 cm depth below the surface. Based on information developed at the Hanover, CRREL, wastewater should not be applied when soil temperature, 2 cm below the surface is less than than 4°C. Application when air temperatures below 0°C is acceptable as long as the soil temperature criteria is met.

Land Area--

The amount of storage and overland flow area required is related and the calculation procedure is as follows:

- Select design seasonal hydraulic loading based on desired preformance
- Find number of aplication days per month
- Find actual monthly hydraulic loading as the product of application days and design loading
- Sum monthly hydraulic loadings
- Use the equation shown under Land Area to find wetted area required for overland flow
- Find volume of wastewater applied per day as product of actual hydraulic loading and wetted area
- Calculate storage requirement as cumulative volume of wastewater available but not applied

Design criteria are presented in Table 43.

TABLE 43. DESIGN CRITERIA FOR EXAMPLE 2

Hydraulic loading, cm/wk	
summer	15
winter	10
Expected BOD^5 removal (mass basis) percent	- 90
Expected SS removal (mass basis) percent	- 90
Application period, hr/d	- 6-8
Application frequency days on/days off	- 5/2
Slope, percent	- 2
Slope length, m	- 40
Number of days air temperature $\leq 0°C$	- 140
Number of days soil temperature $\leq 4°C$	- 100

Land area and storage volume are calculated in Table 44. The land area required from Table 44 is 71 wetted hectares.

Allow 8% for maintenance (see example 1)
71 ha x 1.08 = 77 ha
Allow 10% for collection ditches, and roads
77 ha x 1.10 = 85 ha
Allow 50 m for buffer, assume square site

$$\frac{4\times\sqrt{85 \text{ ha} \times 10{,}000}}{10{,}000} \times 50 = 18 \text{ ha}$$

Total area required = 85 + 18 = 103 ha

Water Balance--

The water balance for Example 2 is given in Table 45.

TABLE 44. EXAMPLE 2 - FACILITIES SIZING

Month	Wastewater flowrate $m^3 \times 10^3$	Days w/ soil temp. <4°C	Applied days	Design hydraulic loading cm	Actual hydraulic loading cm	Wastewater applied $m^3 \times 10^3$	Storage $m^3 \times 10^3$
January	304*	20	10.4	43§	15	113	173
February	304	20	10.4	43	15	113	364
March	304	20	10.4	43	15	113	555
April	304	15	15.4	43	22	165	746
May	304	5	25.4	43	36	270	885
June	304	0	30.4	65†	65	488	919#
July	304	0	30.4	65	65	488	735
August	304	0	30.4	65	65	488	551
September	304	0	30.4	65	65	488	367
October	304	0	30.4	65	65	488	183
November	304	5	25.4	43	36	270	0
December	304	15	15.4	43	22	165	34
	3,650	100	265		486	3,650	

* Equivalent to 10,000 m^3/d assuming 30.4 d/mo

§ Equivalent to 10 cm/wk

† Equivalent to 15 cm/wk

$$A = \frac{3.65\ (10,000)}{486} = 71 \text{ ha}$$

# Storage required

TABLE 45. WATER BALANCE - EXAMPLE 2

Month	P Precipitation cm	H Hydraulic loading cm	ET Evapotranspiration cm	Wp Percolation cm	R Runoff cm	R Runoff $m^3 x 10^3$	R Runoff % of H
Jan	9.80	15	0.00	5	19.8	149	132
Feb	11.3	15	0.00	5	21.3	160	142
Mar	6.05	15	1.98	5	14.1	106	94
Apr	6.12	22	4.67	5	18.5	139	84
May	5.34	36	5.32	5	31.0	233	86
June	4.62	65	14.3	5	50.3	377	77
July	3.98	65	16.2	5	47.8	359	74
Aug	2.17	65	16.0	5	46.2	347	71
Sept	8.60	65	8.70	5	59.9	449	92
Oct	9.37	65	3.56	5	65.8	494	101
Nov	8.78	36	1.52	5	38.3	287	106
Dec	10.6	22	0.00	5	27.6	207	125
	86.7	486	72.3	60	441	3,310	91

Effluent Characteristics--

The storage provided in this example will be in the form of oxidation ponds. BOD reduction will occur in these ponds so that the BOD concentration applied to the overland flow field will be less during the times wastewater is removed from the ponds and added to the incoming raw sewage. BOD concentration to the field can be calculated as follows:

$$BOD_a = \frac{BOD_p\ (Q_p) + BOD_i\ (Qi)}{Q_p + Qi} \qquad (11)$$

BOD_a = BOD_5 applied to field, mg/L
BOD_p = BOD_5 of pond effluent, mg/L
BOD_i = BOD_5 of raw wastewater, mg/L
Q_p = Flow from pond, m^3/mo
Qi = Influent flowrate of raw wastewater, m^3/mo

Because the ponds are used for storage they will have a variable volume and a variable influent and effluent flowrate. This complicates the determination of BOD removal in the oxidation ponds. One method is given in Reference 25. A conservative approach would be to assume no reduction occurs or that some minimal reduction occurs only during the summer months. Values for BOD reduction given in Table 46 were calculated with the method of Reference 25. BOD reductions on the overland flow field were based on 90 percent removal (mass basis) year-round.

Design Example 3 - Southern United States

The objective in this case is to meet the discharge standard of 10 mg/L nitrogen. Oxidation ponds with a minimum of 30 days storage are provided as pretreatment before land application. Design criteria is given in Table 47.

TABLE 46. BOD_5 REDUCTION - EXAMPLE 2

	Applied raw wastewater		Pond effluent		Overland flow influent			Overland flow effluent		
	Flow	BOD_5	Flow	BOD_5	Flow	BOD_5		Flow	BOD_5	
Mo.	m^3x10^3	mg/L	m^3x10^3	mg/L	m^3x10^3	mg/L	kgx10^3	m^3x10^3	kg	mg/L
Jan	113	250	0	250	113	250	28	149	2.8	19
Feb	113	250	0	250	113	250	28	160	2.8	18
Mar	113	250	0	250	113	250	28	106	2.8	26
Apr	165	250	0	250	165	250	28	139	2.8	20
May	270	250	0	230	270	250	68	233	6.8	29
Jun	304	250	184	180	488	223	109	377	10.9	29
July	304	250	184	84	488	187	81	359	8.1	23
Aug	304	250	184	37	488	169	82	347	8.2	24
Sept	304	250	184	14	488	161	79	449	7.9	18
Oct	304	250	184	5	488	158	77	494	7.7	16
Nov	270	250	0	250	270	250	68	287	6.8	24
Dec	165	250	0	250	165	250	41	207	4.1	20

TABLE 47. DESIGN CRITERIA - EXAMPLE 3

Oxidation pond, detention time, days -	30
Overland flow, Hydraulic loading rate	
summer, cm/wk -	12
winter, cm/wk -	7
Expected nitrogen removal	
summer, percent -	90
winter, percent -	75
Application period, hr/day -	6-8
Application frequency - days/days off	5/2
Slope, percent -	2
Slope, length, m -	30

Land Area--

Land requirements are calculated as in example 2 and are presented in Table 48. The volume of ponds required are found as the sum of required storage and the minimum 30 day volume.

TABLE 48. EXAMPLE 3 - FACILITIES SIZING

Month	Wastewater flowrate $m^3 \times 10^3$	Days w/ soil temp. <4°C	Application days cm	Design hydraulic loading cm	Actual hydraulic loading cm	Wastewater applied $m^3 \times 10^3$	Storage $m^3 \times 10^3$
January	304	8	22.4	30.4(7 cm/wk)	22.4	184	675
February	304	6	24.4	30.4	24.4	200	779
March	304	3	27.4	30.4	27.4	225	858
April	304	0	30.4	30.4	30.4	249	913*
May	304	0	30.4	52.1(12 cm/wk)	52.1	427	790
June	304	0	30.4	52.1	52.1	427	667
July	304	0	30.4	52.1	52.1	427	544
August	304	0	30.4	52.1	52.1	427	421
September	304	0	30.4	52.1	52.1	427	300§
October	304	1	29.4	30.4	29.4	241	363
November	304	3	27.4	30.4	27.4	241	426
December	304	9	21.4	30.4	21.4	171	555
	3,650	30			443	3,650	

* Required storage volume

§ 30 day storage

Minimum Storage = 30 d x 10,000 m^3/d = 300 x 10^3 m^3

$$A = \frac{3.65(10,000)}{443} = 82 \text{ ha}$$

Allow 8% for maintenance
      82(1.08) = 89 ha
Allow 10% for ditches and roads
      89(1.10) = 98 ha
Allow 50 m for buffer zone, assume square site

$$\frac{4 \times 50 \quad 98 \times 10,000}{10,000} = 20 \text{ ha}$$

Total area required = 20 + 98 = 118 ha

Water Balance--

The water balance for example 3 is given in Table 49.

TABLE 49. DESIGN EXAMPLE 3 - WATER BALANCE

Month	P Precipitation cm	H Hydraulic loading cm	ET Evapotranspiration cm	Wp Percolation cm	R Runoff cm	 m^3x10^3	 % of H
Jan	15.0	22.4	0.59	7	29.8	244	133
Feb	15.0	24.4	0.64	8	30.8	253	127
Mar	13.3	27.4	1.08	8	31.6	259	115
Apr	7.44	30.4	2.65	9	26.2	215	86
May	14.2	52.1	4.99	7	54.3	445	104
June	14.8	52.1	7.70	7	52.2	428	100
July	10.9	52.1	7.91	8	47.1	386	90
Aug	1.98	52.1	8.63	6	39.5	324	76
Sept	20.2	52.1	5.06	7	60.2	494	116
Oct	9.04	29.4	3.51	8	26.9	221	92
Nov	16.0	27.4	1.69	8	33.7	276	115
Dec	6.91	21.4	0.57	8	19.7	162	93
	145	443	45.0	91	452	3,710	102

Effluent Characteristics--

In example 2 only a portion of the total flow passed through the storage oxidation ponds. In this example all influent wastewater receives at least 30 days of treatment in oxidation ponds. Nitrogen will be removed to some degree in the ponds depending on the temperature and detention time. As in example 2, the method for determining nitrogen removal through the pond is beyond the scope of this report. In this example the method given in Reference 25 was used. The nitrogen reduction for example 3 is given in Table 50.

TABLE 50. EXAMPLE 3 - NITROGEN REMOVAL

	Raw wastewater		Pond effluent		Overland flow influent			Overland flow effluent		
Mo.	Flow m^{3}x10^3	Nitrogen mg/L	Flow m^{3}x10^3	Nitrogen mg/L	Flow m^{3}x10^3	Nitrogen mg/L	Nitrogen kgx10^3	Flow m^{3}x10^3	Nitrogen* kgx10^3	Nitrogen* mg/L
Jan	304	50	184	33	184	33	6.07	244	1.56	6.4
Feb	304	50	200	37	200	37	7.40	253	1.89	7.5
Mar	304	50	225	38	225	38	8.6	259	2.15	8.3
Apr	304	50	249	35	249	35	8.72	215	0.87	4.2
May	304	50	427	26	427	26	11.1	445	1.11	2.6
Jun	304	50	427	22	427	22	9.39	428	0.94	2.3
July	304	150	427	17	427	17	7.26	386	0.73	1.9
Aug	304	50	427	17	427	17	7.26	324	0.73	2.3
Sept	304	50	427	15	427	15	6.41	494	0.64	1.3
Oct	304	50	241	22	241	22	5.30	221	1.31	5.9
Nov	304	50	241	23	241	23	5.54	276	1.39	5.0
Dec	304	50	175	31	175	31	5.43	162	1.39	8.6

*90 percent removal Apr-Sept, 75 percent removal Oct-Mar.

Cost Estimate--

Costs for all examples were made using the cost curves included in Appendix A. Capital cost estimates are shown in Table 51. Costs for chlorination facilities were included for examples 1 and 2 because raw wastewater is applied directly to the land and there is a chance of pathogens entering the receiving water through the runoff. In example 3 all wastewater receives a minimum of 30 days storage in oxidation ponds where pathogens would be effectively removed prior to land application.

TABLE 51. CAPITAL COST ESTIMATE - DESIGN EXAMPLES

	1	2	3
Raw wastewater pumps	$ 700,000	$ 700,000	$ 700,000
Forcemains	20,000	20,000	20,000
Oxidation ponds		1,727,000	1,727,000
Land @ $2,500/ha	175,000	259,000	291,000
Field preparation			
-site clearing	25,000	30,000	35,000
-terrace construction	300,000	550,000	600,000
Distribution piping	25,000	37,000	42,000
Chlorine contact basins	50,000	50,000	
Chlorine feed and storage facilities	30,000	30,000	
Collection ditches	45,000	60,000	70,000
Lined channels	91,000	109,000	121,000
Totals	$1,461,000	$3,567,000	$3,606,000

As shown in Table 51, the need for storage greatly increases the capital costs for overland flow systems.

SECTION VI

STATE REGULATIONS

About half of the states have guidelines or regulations dealing with land treatment of wastewater[26]. These cover the topic to varying degrees, with some being quite general and others being more specific. Some of the states have flexible regulations while others have strict guidelines to be followed. Many of the states without formal regulations have policies of reviewing land application projects on a case by case basis.

A major source of controversy regarding overland flow is classification as a land application method or as a treatment method. Many states do not consider the treatment capabilities of vegetation and soil so land application is viewed as a means of disposal, requiring conventional primary or secondary treament prior to application. This philosophy does not really apply to overland flow since runoff is collected from the site and subsequently disposed of. In this case, the upper layers of soil and the vegetative cover provide treatment of the wastewater and extensive pretreatment is not generally necessary.

Of the states with guidelines regulating land application, most are directed toward irrigation and infiltration-percolation. This can be attributed to the fact that overland flow has only recently received attention as a viable method of treating domestic wastewater. As overland flow becomes a more popular treatment practice, federal and state governments should develop guidelines to regulate design and operation.

Recently, the State of Maryland adopted a set of design guidelines for land treatment[27]. These guidelines are intended to help planners and designers with the implementation of new land treatment facilities. The general philosophy associated with the guidelines is that they should be as flexible as possible as long as the public health is protected. Those sections of the guideline pertaining to land treatment in general and specifically to overland flow have been included in Appendix A. Among the topics covered in the guidelines are site selection, preapplication treatment, storage, surface drainage and buffer zones, equipment requirements, monitoring and crop management. Draft guideline for land treatment systems for the State of Mississippi are included as Appendix B. They have not yet been adopted.

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

- Overland flow systems effectively treat raw municipal wastewater with resulting effluent quality better than secondary standards.

- Overland flow systems resemble conventional attached growth biological systems and apparently exhibit first order kinetics.

- Predictive relationships among the process design, operating parameters, and treatment performance have not been developed at this time.

- In general, the following treatment efficiencies have been observed:

	% reduction
BOD	90+
SS	90+
Nitrogen	70-90
Phosphorus	40-80
Fecal Coliform	90-99.6

These reductions apply with all types of applied wastewaters if hydraulic loadings are adjusted for different preapplication treatment levels.

- Phosphorus removal may be enhanced with alum addition (1-2 mg alum/mg phosphorus)

- There is enough information available to provide conservative design of overland flow systems. More information is necessary to develop cost effective designs.

RECOMMENDATIONS

- Conduct more pilot and full scale study to determine critical design and operating parameters. Existing systems could be studied for information not reported in the literature.

- Combine this information with results of Corps of Engineers work to be published in the Spring of 1980.

- Conduct studies to determine the effects of precipitation on process performance.

- Further work on nitrogen removal mechanisms and process control is necessary.

REFERENCES

1. U.S. Environmental Protection Agency, U. S. Army Corps of Engineers, U.S. Department of Agriculture, Process Design Manual for Land Treatment of Municipal Wastewater, EPA 625/1-77-08 (COE EM 1110-1-501), October, 1977.

2. Smith, R.G. and Schroeder, E.D., "Investigation of Overland Flow Design and Operating Parameter", presented at the Workshop on Overland Flow for Treatment of Municipal Wastewater, Greenville, S.C., November 27-28, 1979.

3. Thomas, R.E., Jackson, K., and Penrod, L., Feasibility of Overland Flow for Treatment of Raw Domestic Wastewater, U.S. Environmental Protection Agency, EPA-660/2-74-087, July 1974.

4. Thomas, R.E., Bledsoe, B., and Jackson, K., Overland Flow Treatment of Raw Wastewater with Enhanced Phosphorus Removal, U.S. Environmental Protection Agency, EPA-600/2-76-131, June 1976.

5. Peters, R.E. and Lee, C.R., "Field Investigations of Advanced Treatment of Municipal Wastewater by Overland Flow", in State of Knowledge in Land Treatment of Wastewater, International Symposium, U.S. Army Corps of Engineers, Hanover, NH, August 1978.

6. Illinois Pollution Control Board (1972) Rules and Regulations.

7. Asaturians, A. (1977), "Overland Flow as Advanced Treatment for Wastewater", thesis submitted in partial fulfillment of the requirements for the Degree Master of Science in Engineering, Southern Illinois University.

8. Stephen, S.K. (1977), "Nitrogen Removal from Wastewater by Overland Flow", thesis submitted in partial fulfillment of the requirements for the Degree Master of Science in Engineering, Southern Illinois University.

9. Jenkins, T.J., Martel, C.J., Gaskin, D.A., Fisk, D.J., and McKim, H.L., "Performance of Overland Flow Land Treatment in Cold Climates", in State of Knowledge in Land Treatment of Wastewater, International Symposium, U.S. Army Corps of Engineers, Hanover, NH, August, 1978.

10. Martel, C.J., Jenkins, T. F., and Palazzo, A. J., "Wastewater Treatment in Cold Regions by Overland Flow", Preliminary draft.

11. Martel, C.J., Adrian, D.D., Jenkins, T.J., and Peters, R.E., "Rational Design of Overland Flow Systems", Abstract.

12. Hall, D.H. et al, Municipal Wastewater Treatment by the Overland Flow Method of Land Application, U.S. Environmental Protection Agency, EPA-600/2-79-178, August 1979.

13. Sprinkler Irrigation, Sprinkler Irrigation Association, Silver Spring, Md., 1975.

14. Israelsen, O.W. and Hansen, V.E., *Irrigation Principles and Practices*, Wiley, New York, 1962.

15. Abernathy, A. Ray, communication.

16. Gilde, L.C. et al, "A Spray Irrigation System for Treatment of Cannery Wastes," JWPCF Vol. 43, pp 2011-2025, October 1971.

17. Overcash, M.R., "Implications of Overland Flow for Municipal Waste Management," JWPCF, Vol. 50, pp 2337-2347, Oct. 1978.

18. Crites, R. et al, *Process Design Manual for Land Treatment of Municipal Wastewater*, U.S. Environmental Protection Agency, et al, EPA 625/1-77-008, October 1977.

19. Deemer, D.D., "Overland Flow Treatment of Wastewater", presented at the U.S. EPA/Clemson University Workshop Overland Flow for Treatment of Municipal Wastewater, Greenville, SC, Nov 27-28, 1979 (proceedings available through Clemson University).

20. Peters, R.E., et al "Influence of Storm on Nutrient Runoff from Overland Flow Land Treatment Systems," draft report to be published.

21. Seabrook, B.L., *Land Application of Wastewater in Australia, The Werribee Farm System*, U.S. Environmental Protection Agency, May 1975.

22. Tucker, D. et al, *Overland Flow of Oxidation Pond Effluents at Davis, CA*, prepared for U.S. Environmental Protection Agency, January 1977.

23. Atmospheric Administration, "Climatic Summary of the United States".

24. "Consumptive Use of Water and Irrigation Water Requirements", Technical Committee on Irrigation Water Requirements, Irrigation and Drainage Division, ASCE, September 1973.

25. Haith, Douglas A., Koenig, A., and Loucks, D., "Preliminary Design of Wastewater Land Application Systems", *Journal WPCF*, December 1977, 2371.

26. Morris, C.E. and Jewell, W.J., "Regulations and Guidelines for Land Application of Wastes - A 50-State Overview," *Land as a Waste Management Alternative*, Raymond C. Loehr, Ed. Ann Arbor Science, 1977

27. "Design Guidelines for Land Treatment of Domestic Wastewater," Environmental Health Administration, Department of Health and Mental Hygiene, State of Maryland, 1978 Edition.

APPENDIX A

COSTS

Costs for overland flow systems including pre-application treatment are presented in cost curve form as shown in Figures C1 - C13 show construction costs. Operation and maintenance requirements are shown in Figures OM1-OM17. Each system will have differing components. With the cost curves presented, any system cost can be determined by adding the individual component costs. Construction materials and supply costs are current to July 1979.

To use these cost curves the preliminary design must first be determined. Costs are then determined for each unit within the system. These costs are then adjusted to the local conditions by using the appropriate cost index. The cost curves and materials and supplies curves are based on an ENR index of 3052 or EPA index of 346. The energy and labor curves are shown as energy units and labor hours so do not require adjustment.

CONSTRUCTION COST CURVES

Item	Figure Number
Collection ditches	C1
Lined channels	C2
Forcemains	C3
Storage reservoirs 100 - 100,000 m^3	C4
Storage reservoirs 100,000 - 1 x $10^8 m^3$	C5
Field preparation - terrace construction	C6
Field preparation - site clearing	C7
Construction cost for distribution piping	C8
Raw wastewater pumps	C9
Recycle pumping	C10
Aerated grit removal and flow measurement	C11
Chlorine contact basins	C12
Chlorine feed and storage facilities	C13

OPERATION AND MAINTENANCE COST CURVES

Wastewater pumping, labor	OM-1
Wastewater pumping, energy	OM-2
Wastewater pumping, maintenance supply costs	OM-3
Grit removal and flow measurement, labor	OM-4
Grit removal and flow measurement, energy	OM-5
Grit removal and flow measurement, maintenance and supply costs	OM-6
Chlorination, labor	OM-7
Chlorination, energy	OM-8
Chlorination, maintenance materials and supplies	OM-9
Storage reservoirs, 100 - 100,000 m^3 maintenance materials and supplies	OM-10
Storage reservoirs, 100 - 100,000m^3 labor (3 m depth)	OM-11
Storage reservoirs, 100,000 - 1 x $10^8 m^3$ (5 m depth)	OM-12

OPERATION AND MAINTENANCE COST CURVES (Cont'd)

Item	Figure Number
Storage reservoirs, 100,000 - 1 x $10^8 m^3$ maintenance materials and supplies	OM-13
Forcemains, labor	OM-14
Forcemains, maintenance materials and supplies	OM-15
Lined channels, labor	OM-16
Lined channels, maintenance materials and supplies	OM-17

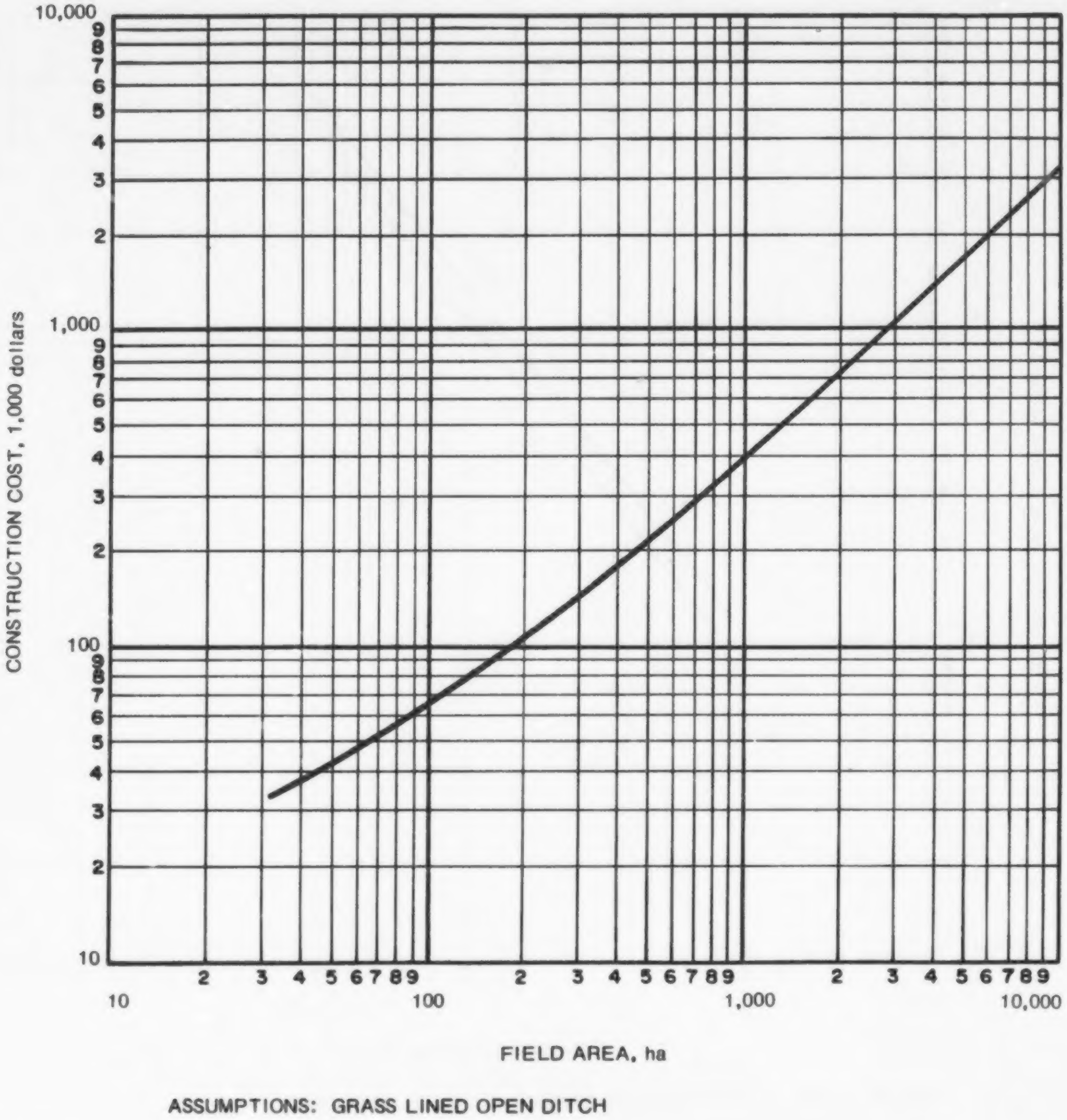


Figure C1. Construction costs for collection ditches.

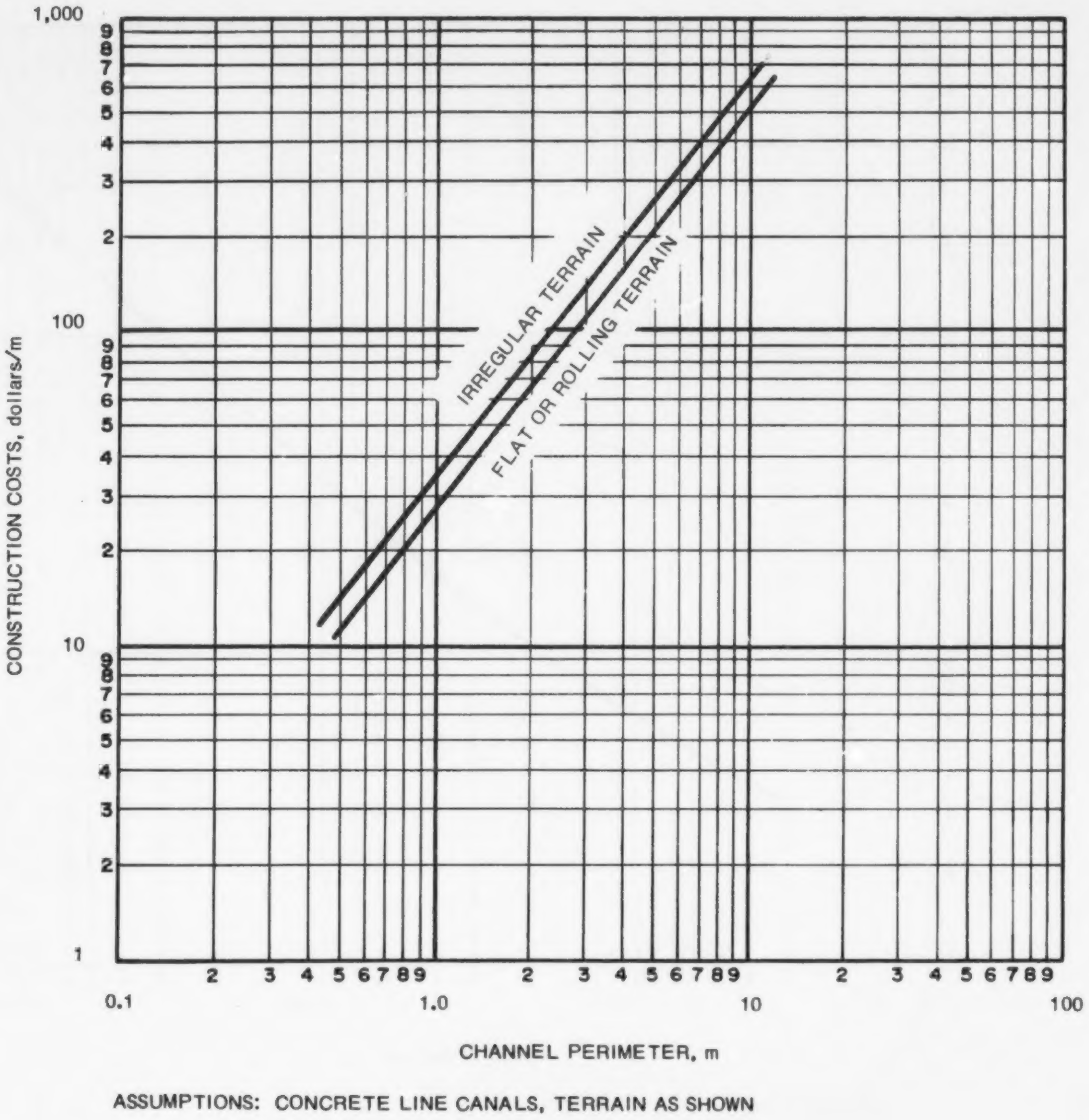
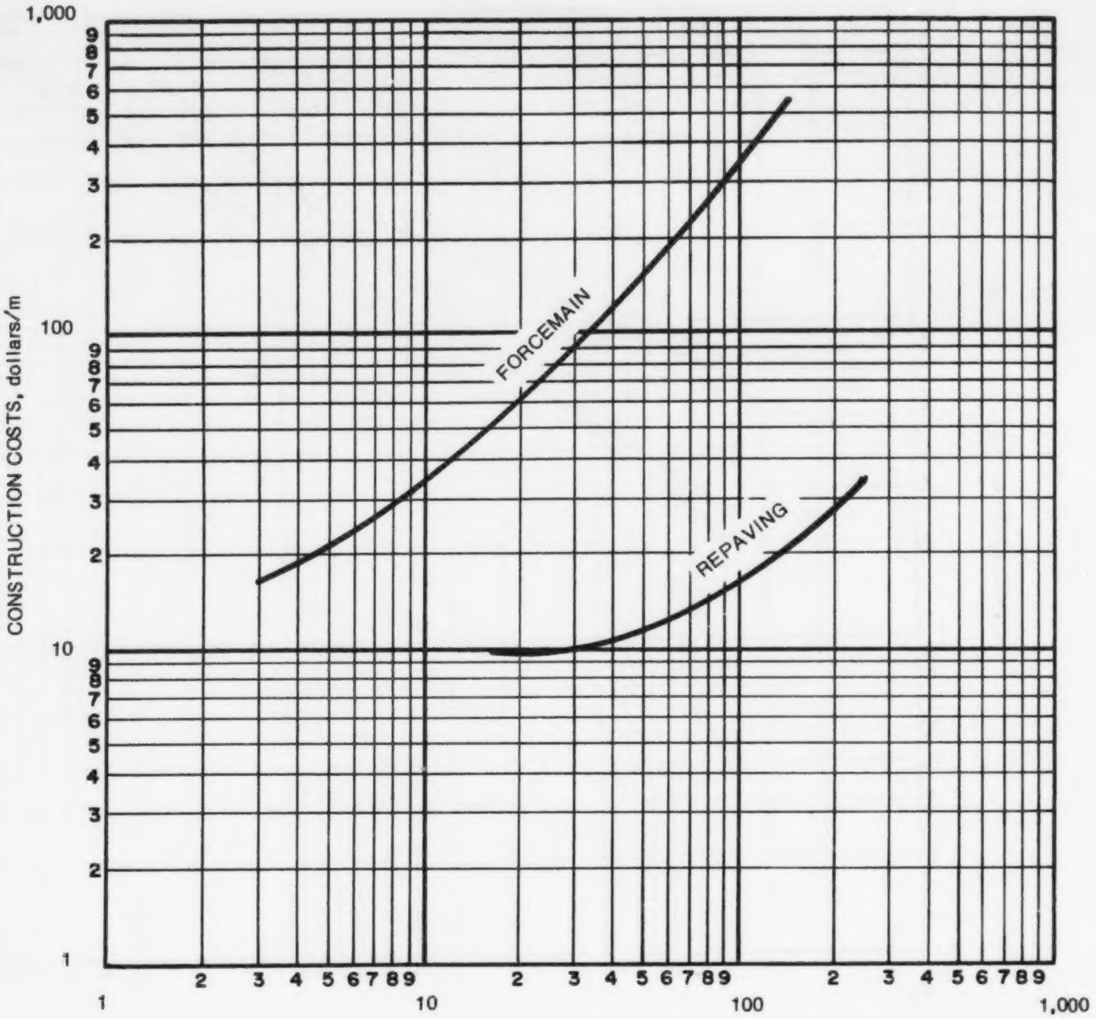
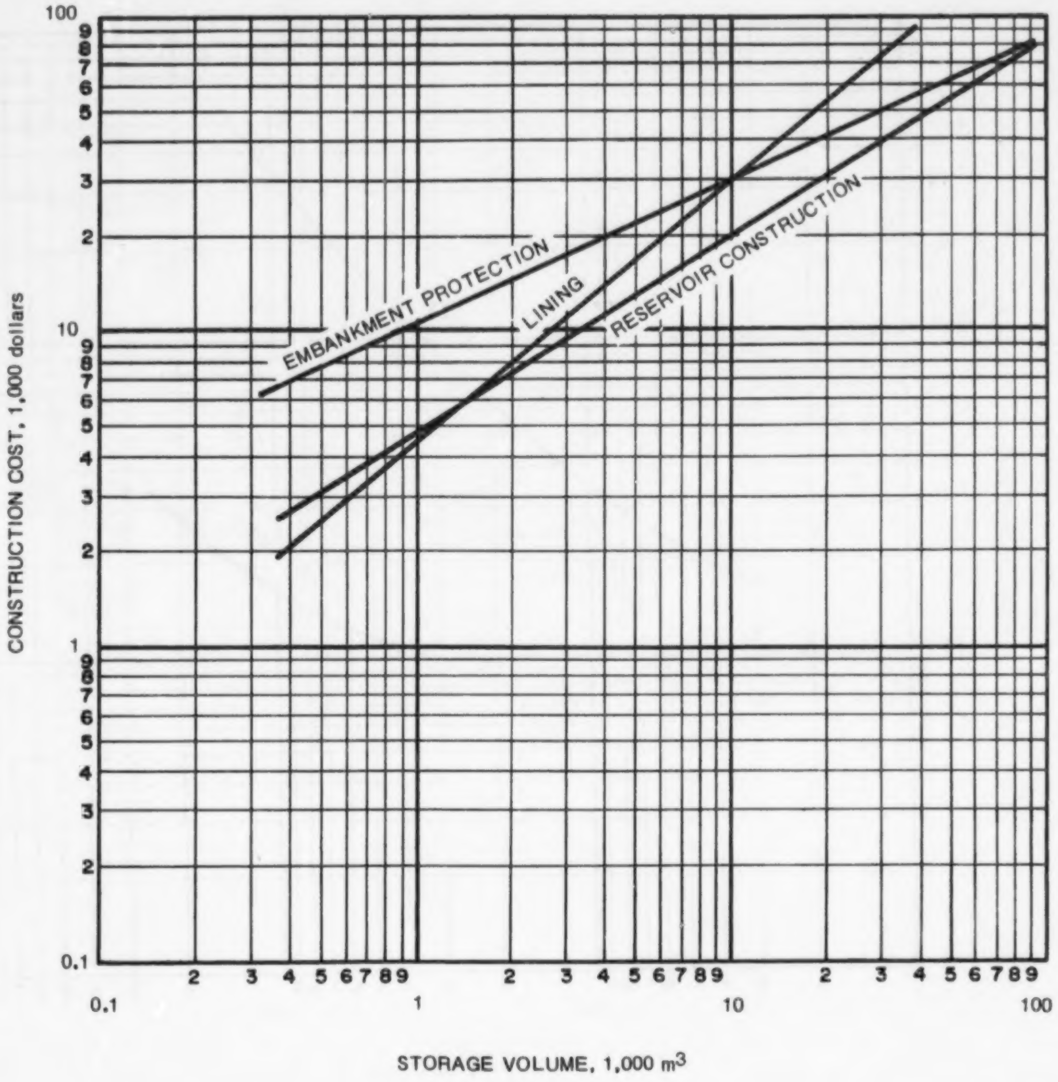


Figure C2. Construction costs for lined channels.



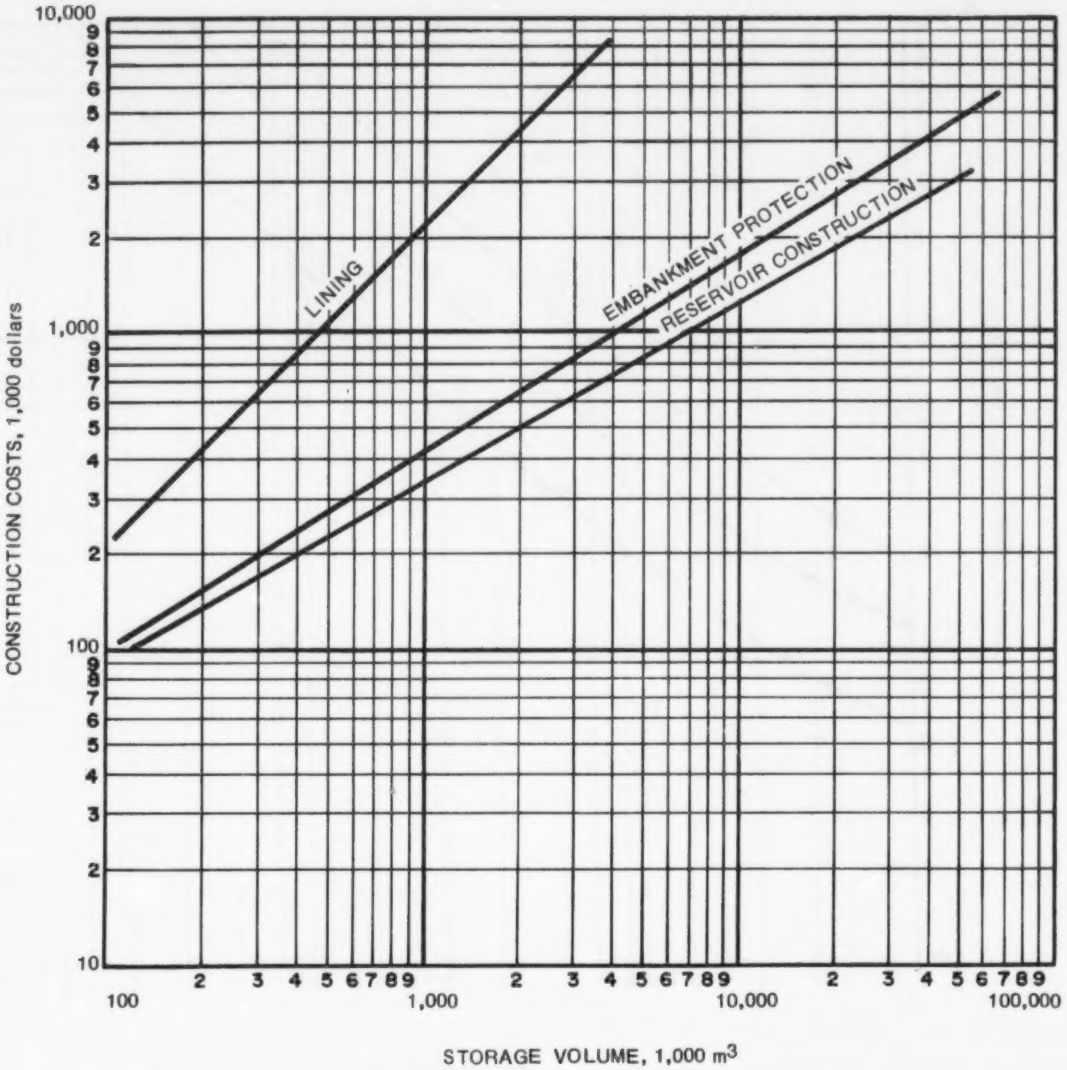
ASSUMPTIONS: CLASS 150 REINFORCED CONCRETE PIPE OR EQUIVALENT. NO MAJOR UTILITY, ROADWAY OR RIVER CROSSINGS.

Figure C3. Construction cost for forcemains.



ASSUMPTIONS: EXTERIOR SLOPE 2:1, INTERIOR SLOPE 3:1. MATERIALS ACQUIRED LOCALLY
3m WATER DEPTH

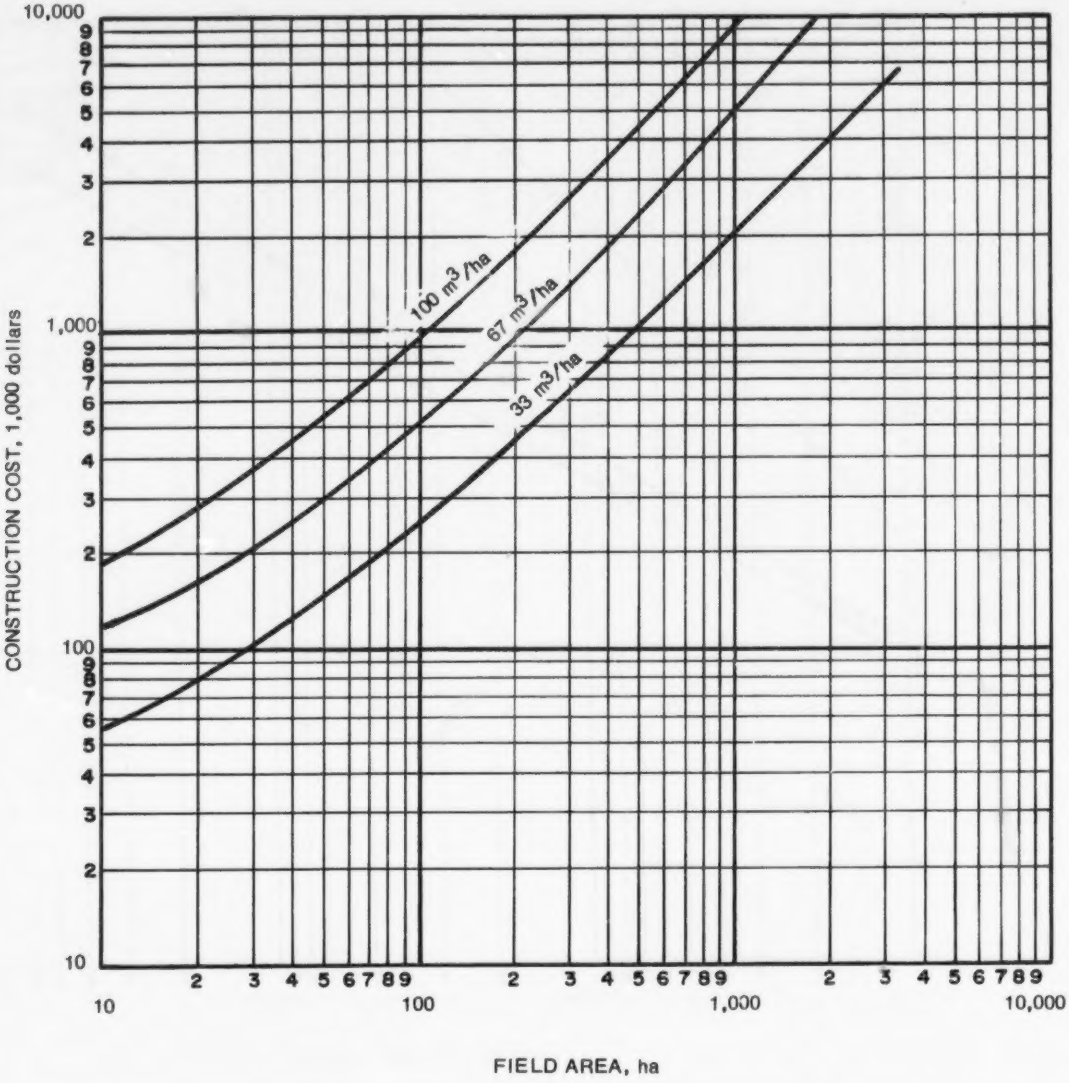
Figure C4. Construction costs for storage reservoirs. (100-100,000 m^3)



ASSUMPTIONS: EXTERIOR SLOPE 2:1, INTERIOR SLOPE 3:1. MATERIALS ACQUIRED LOCALLY

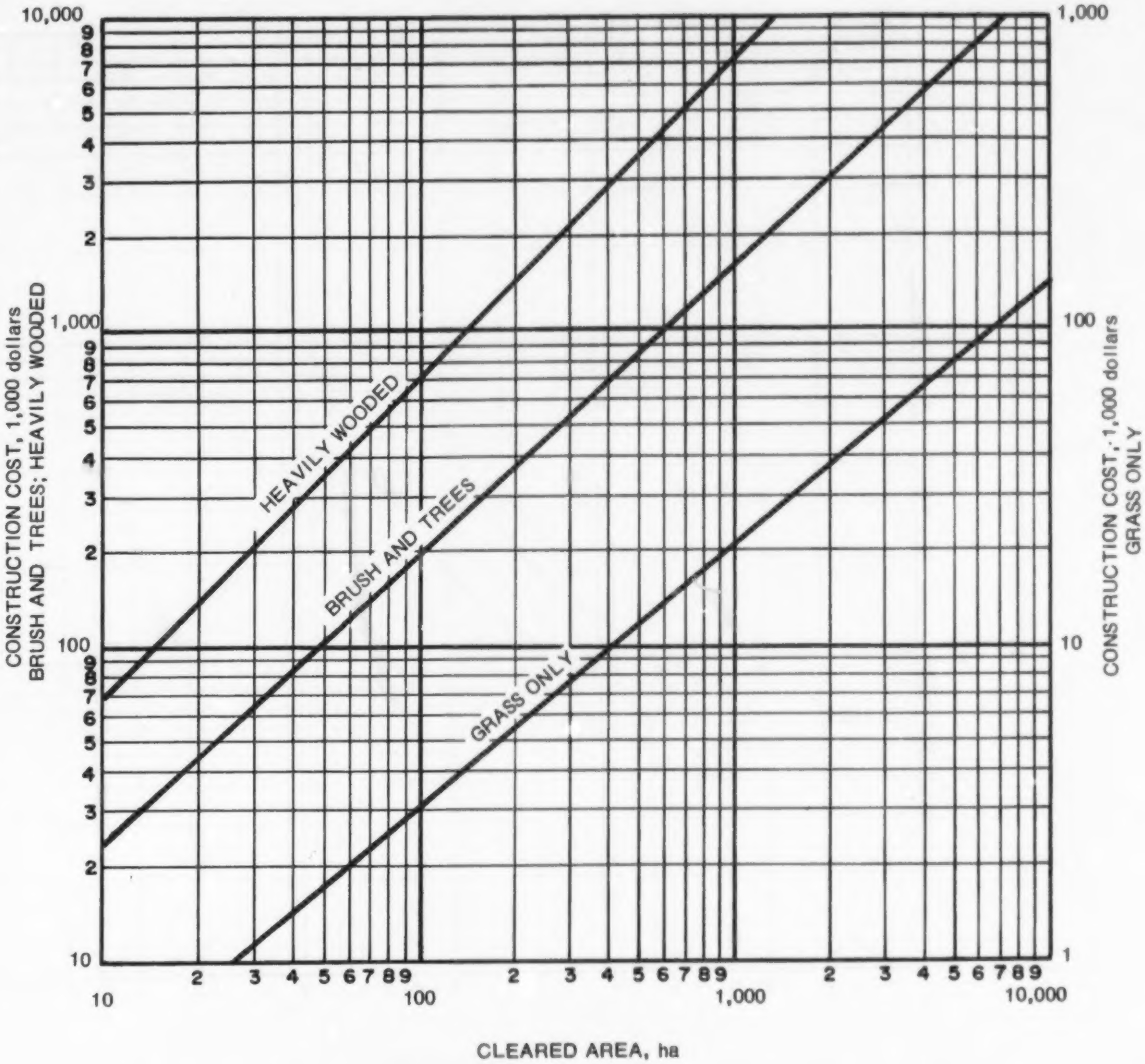
5m WATER DEPTH

Figure C5. Storage reservoirs. (100,000-100,000,000 m^3)



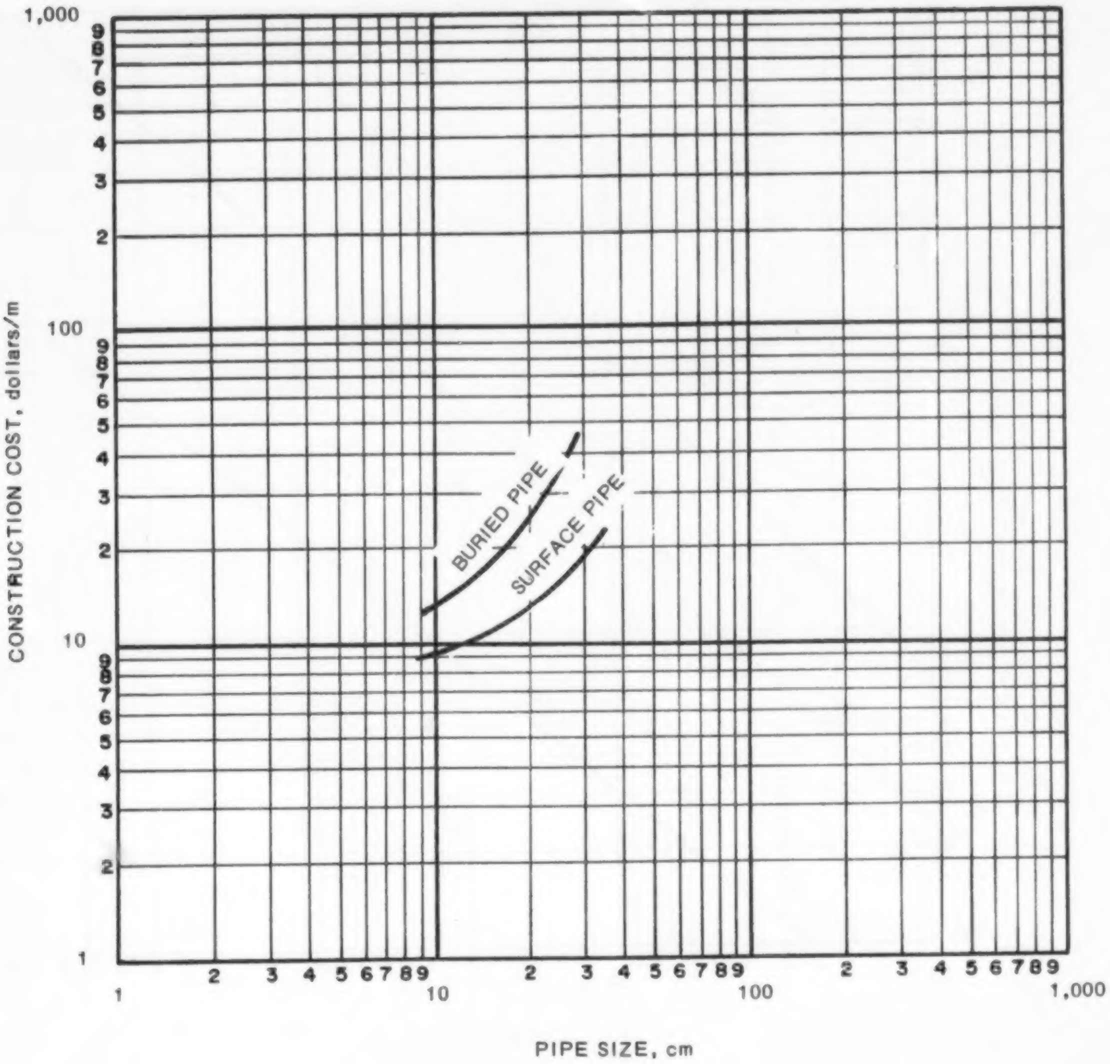
ASSUMPTION: MATERIAL CUT & FILL ESSENTIALLY BALANCED WITHIN SITE BOUNDARIES

Figure C6. Field preparation - terrace construction.



ASSUMPTION: CLEARED MATERIAL PUSHED TO EDGE OF SITE OR DISPOSED OF WITHIN SITE

Figure C7. Field preparation - site clearing.



ASSUMPTIONS: BURIED PIPE IS PLASTIC, SURFACE PIPE IS ALUMINUM

Figure C8. Construction cost for distribution piping.

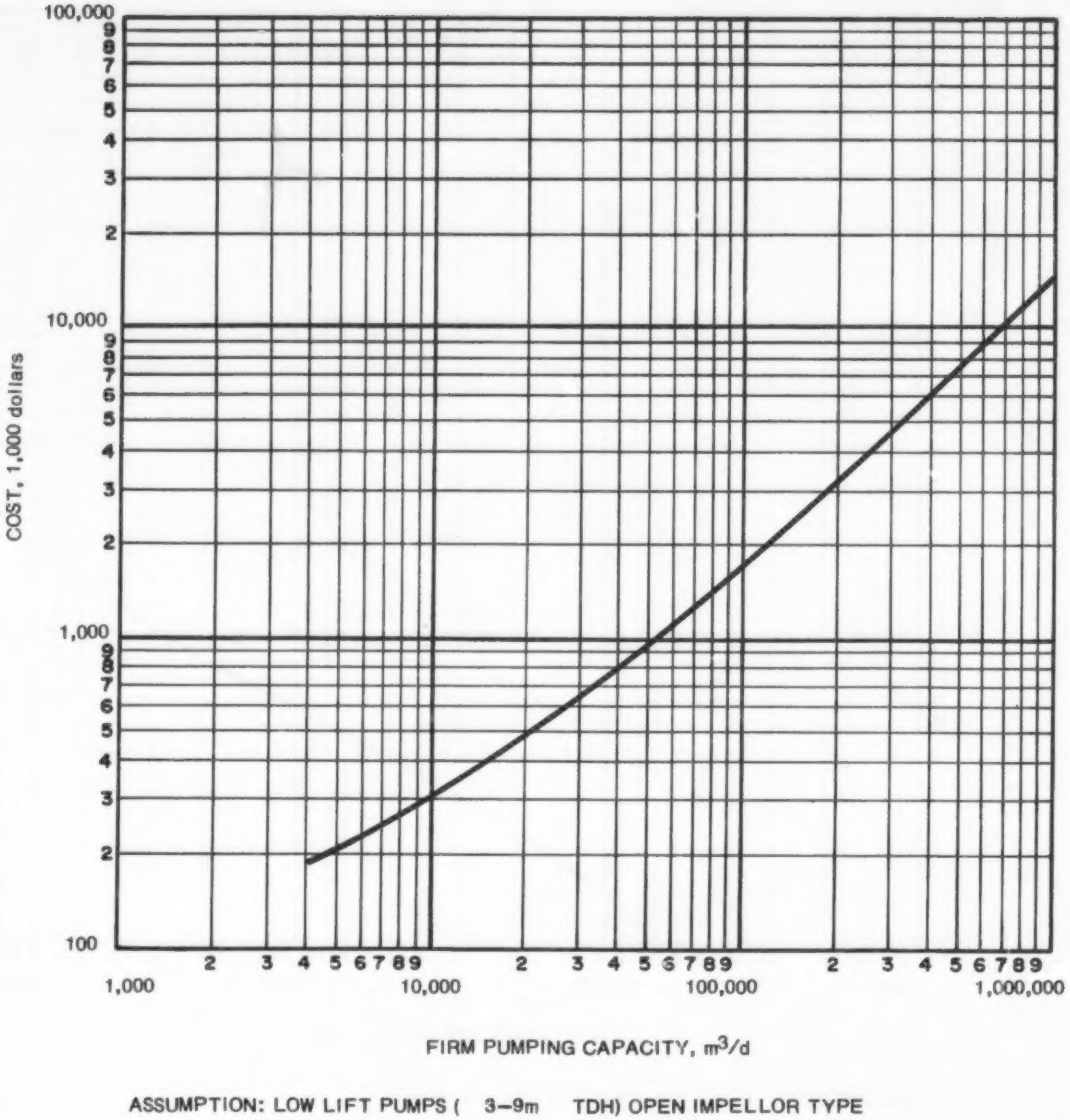
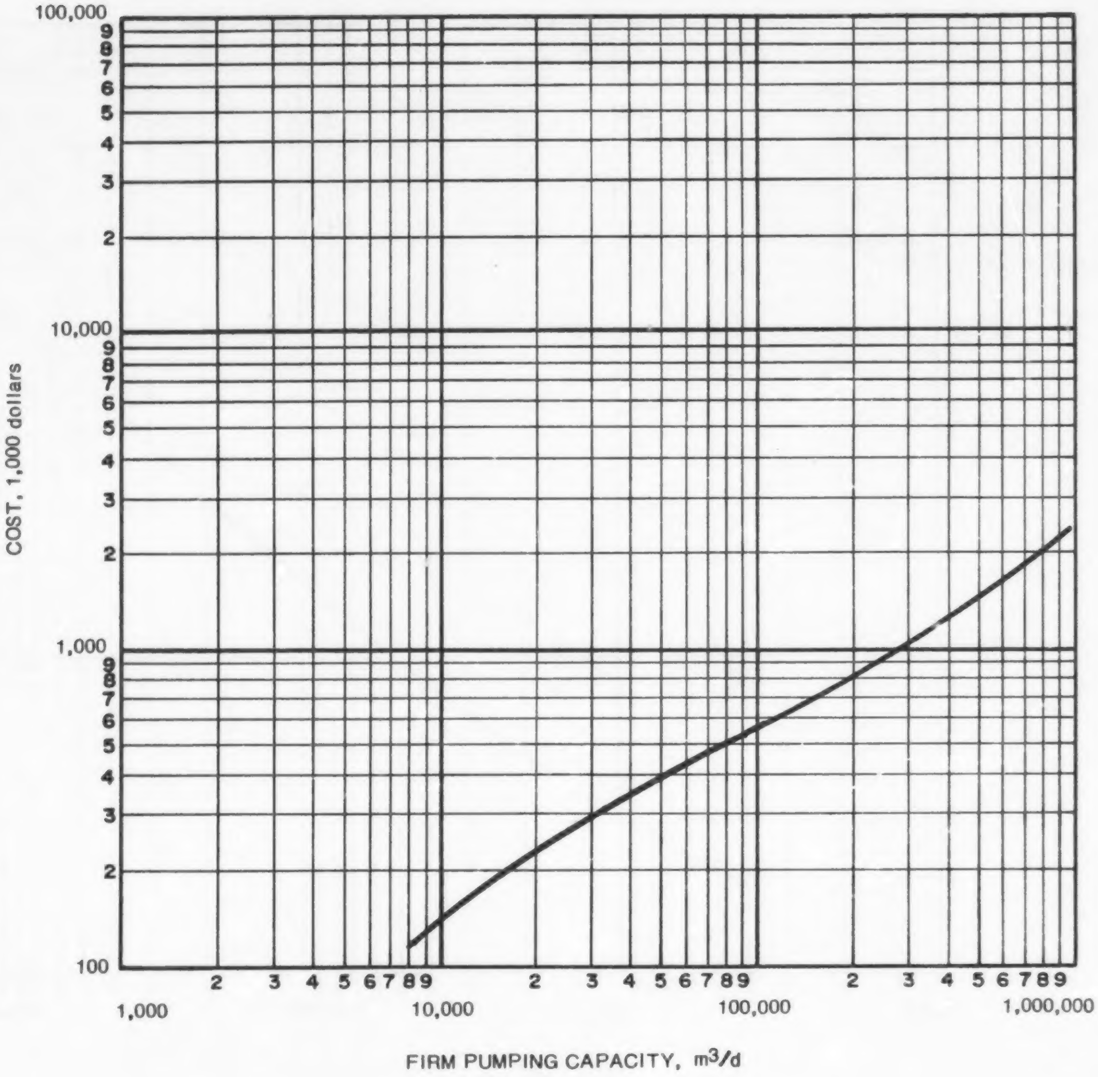
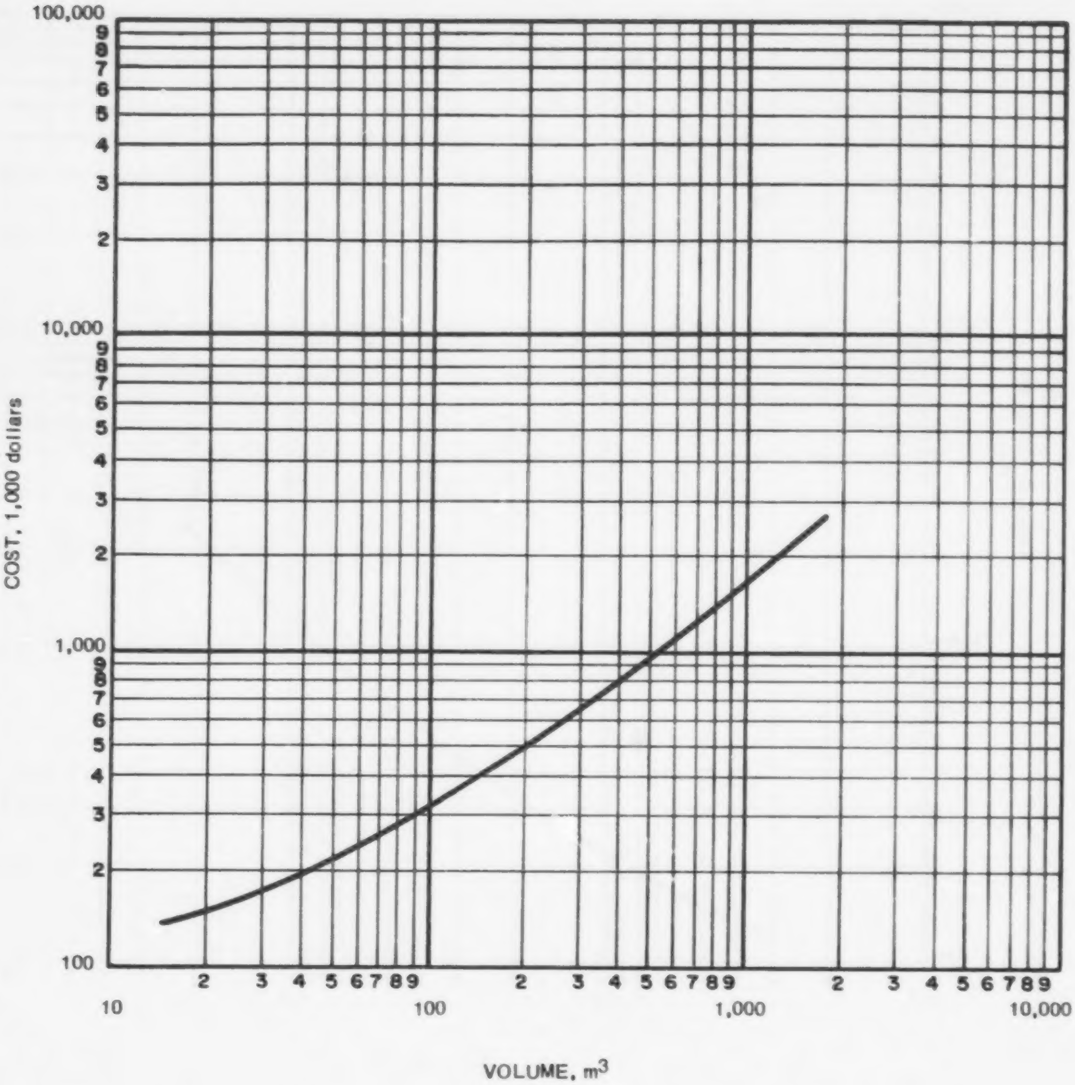


Figure C9. Construction costs for raw wastewater pumps.



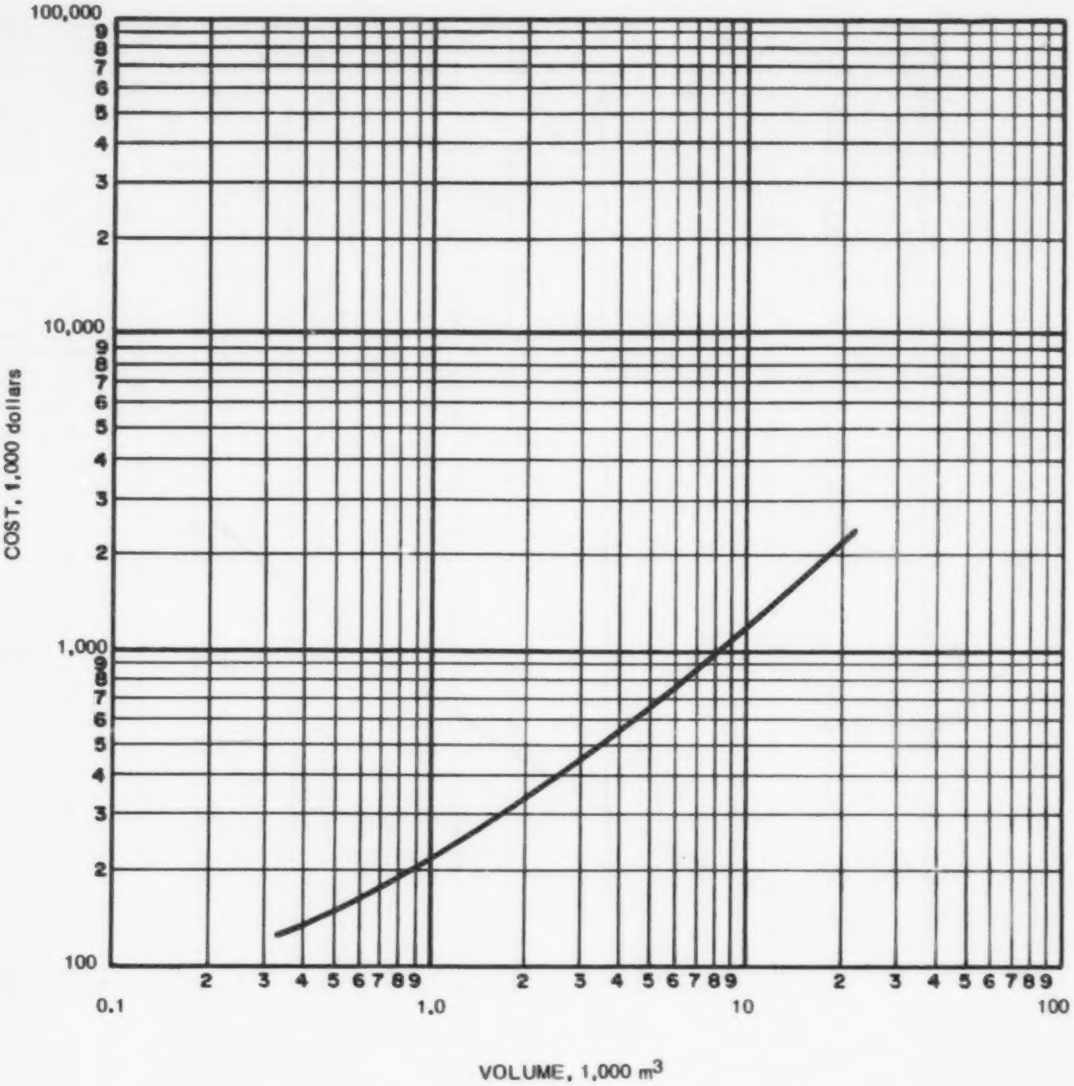
ASSUMPTIONS: LOW LIFT, CENTRIFUGAL PUMPS

Figure C10. Construction costs for in-plant and recycle pumping.



ASSUMPTIONS: GRIT REMOVAL FOR SEWER WITHOUT STORM WATER INFLUENCE

Figure C11. Construction cost for aerated grit removal and flow measurement.



ASSUMPTIONS: BASIN VOLUME PROVIDES 30 MIN DETENTION TIME AT PEAK DAILY FLOW

Figure C12. Construction cost for chlorine contact basins.

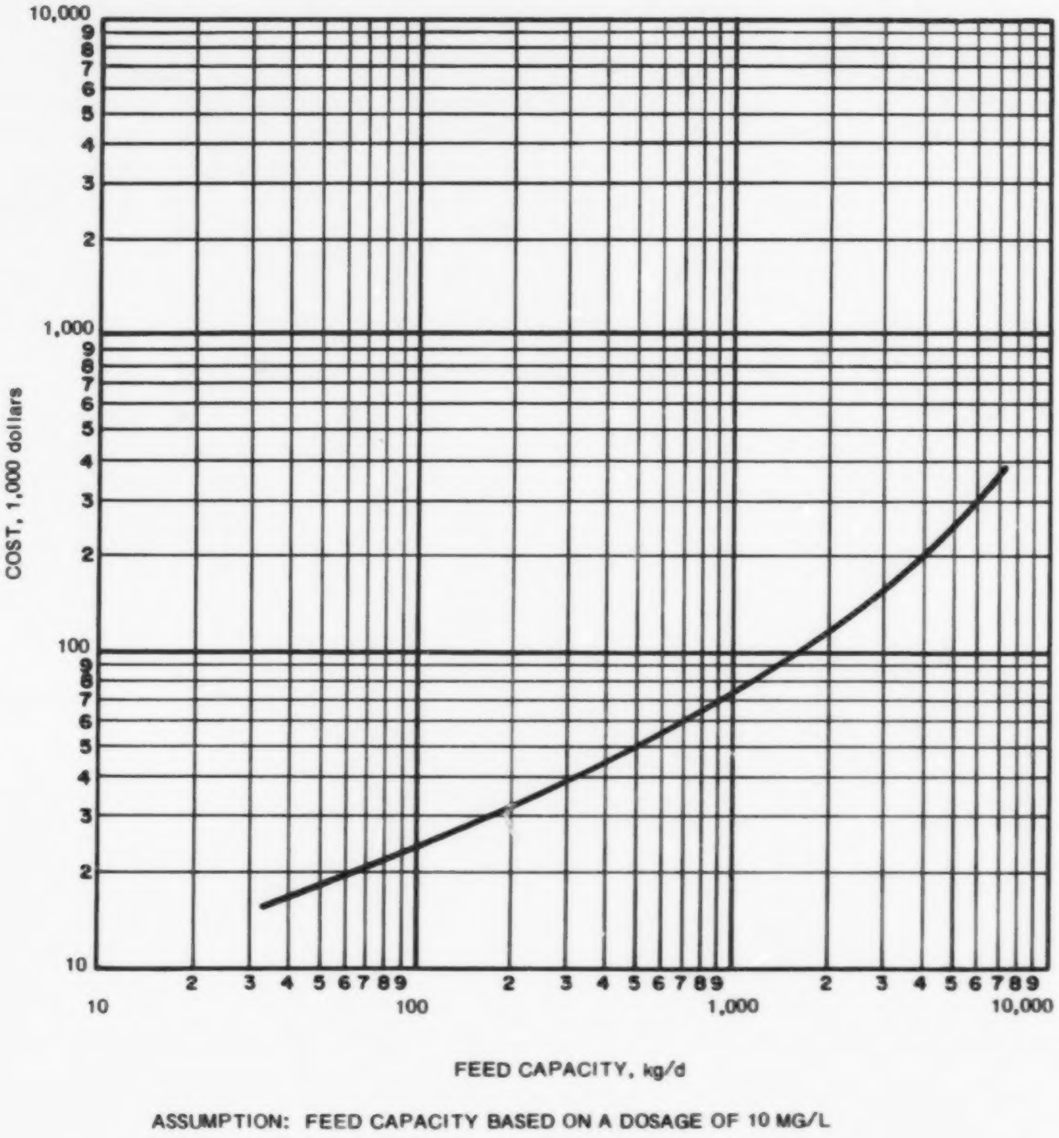


Figure C13. Construction costs for chlorine feed and storage facilities.

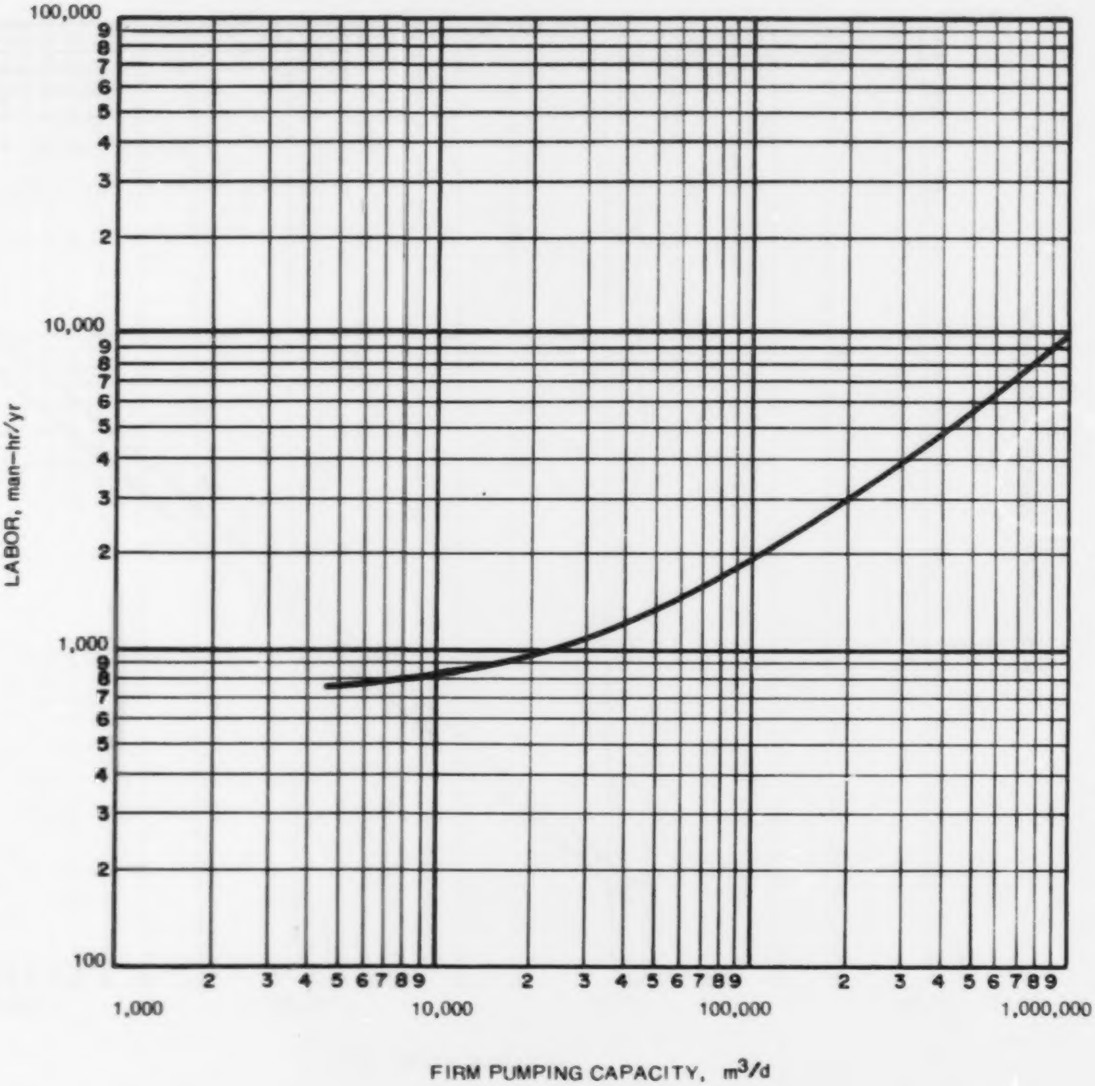


Figure OM1. Labor requirements for wastewater pumping.

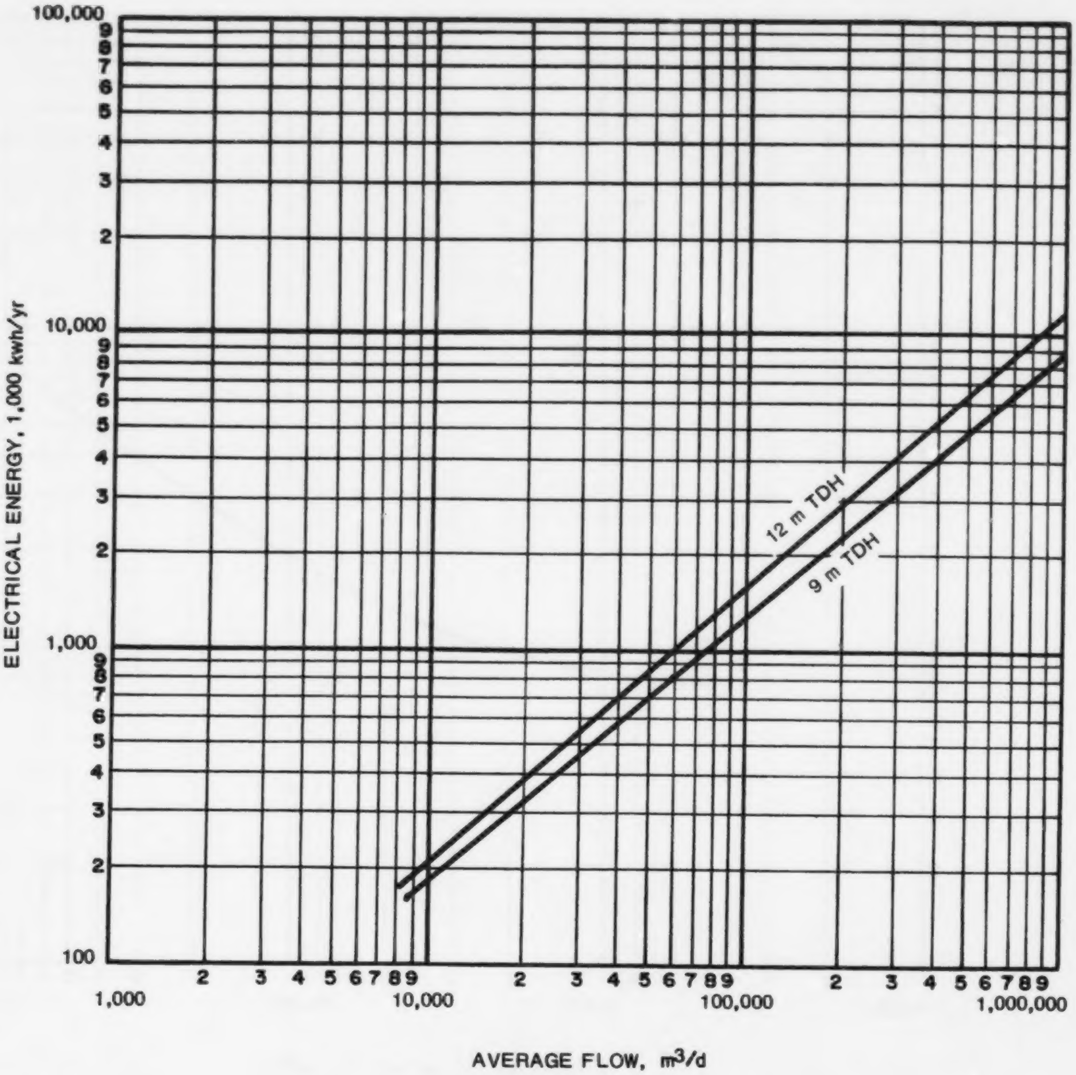


Figure OM2. Energy requirements for wastewater pumping.

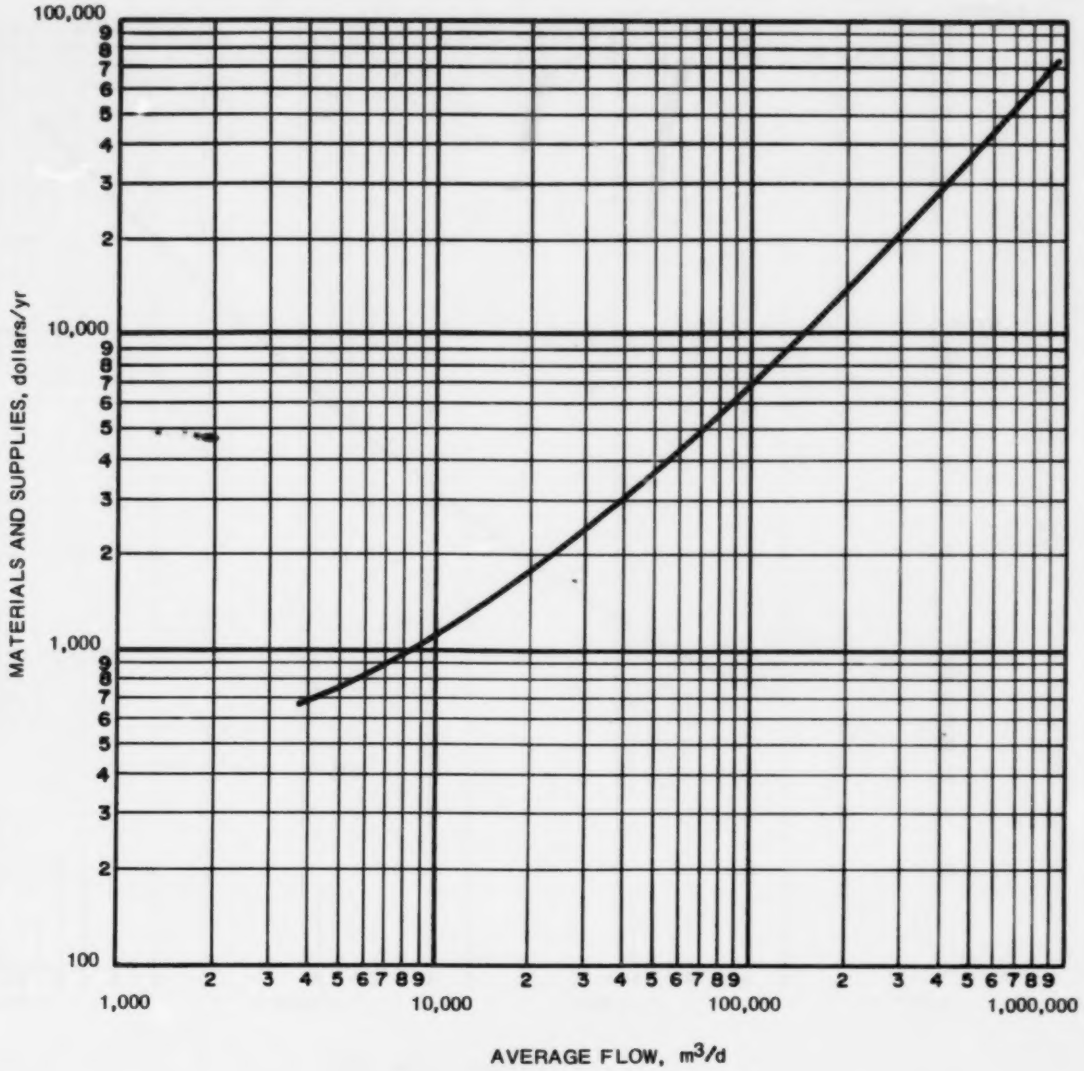


Figure OM3. Maintenance material and supply costs for wastewater pumping.

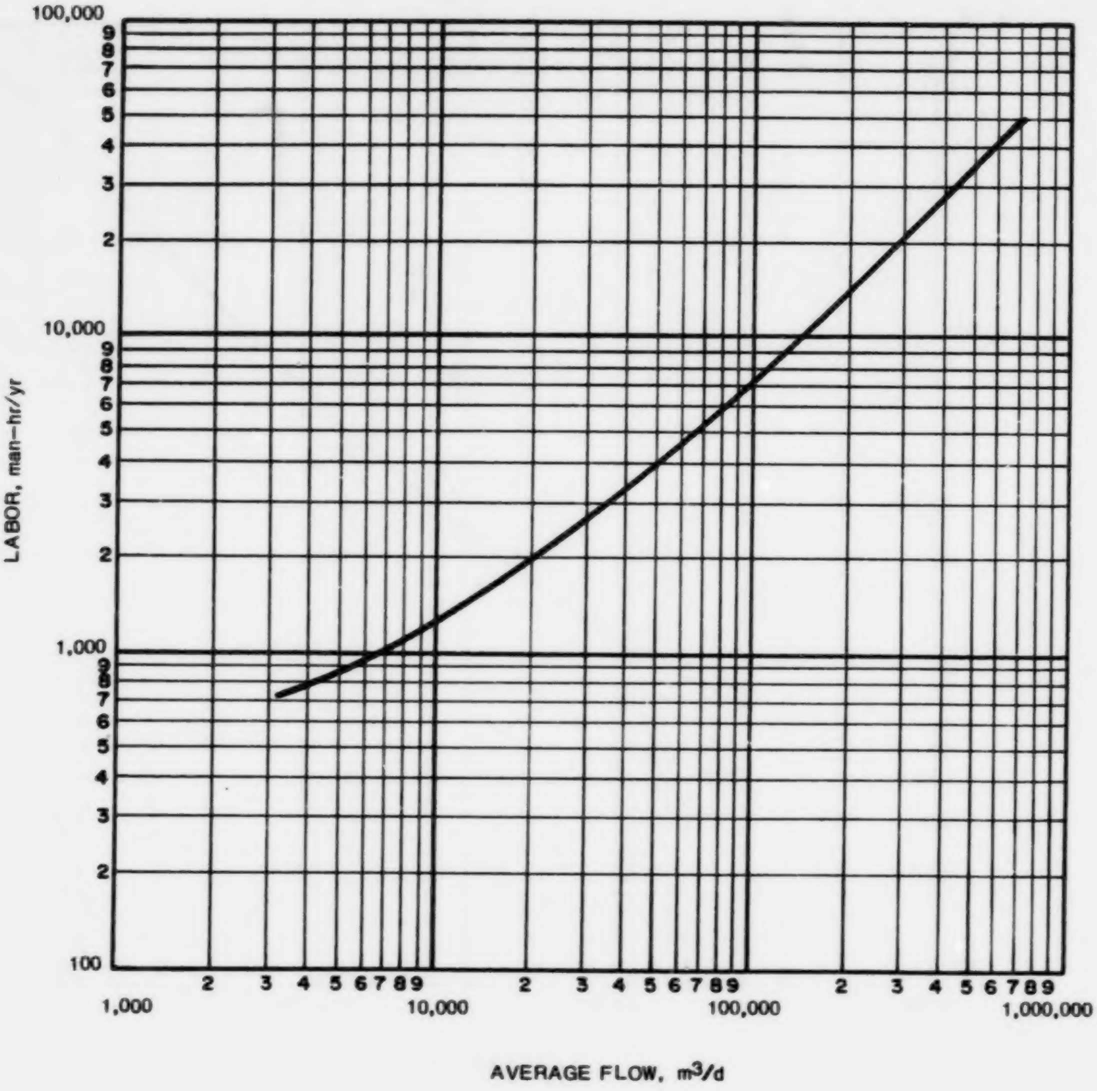


Figure OM4. Labor requirements for grit removal and flow measurement.

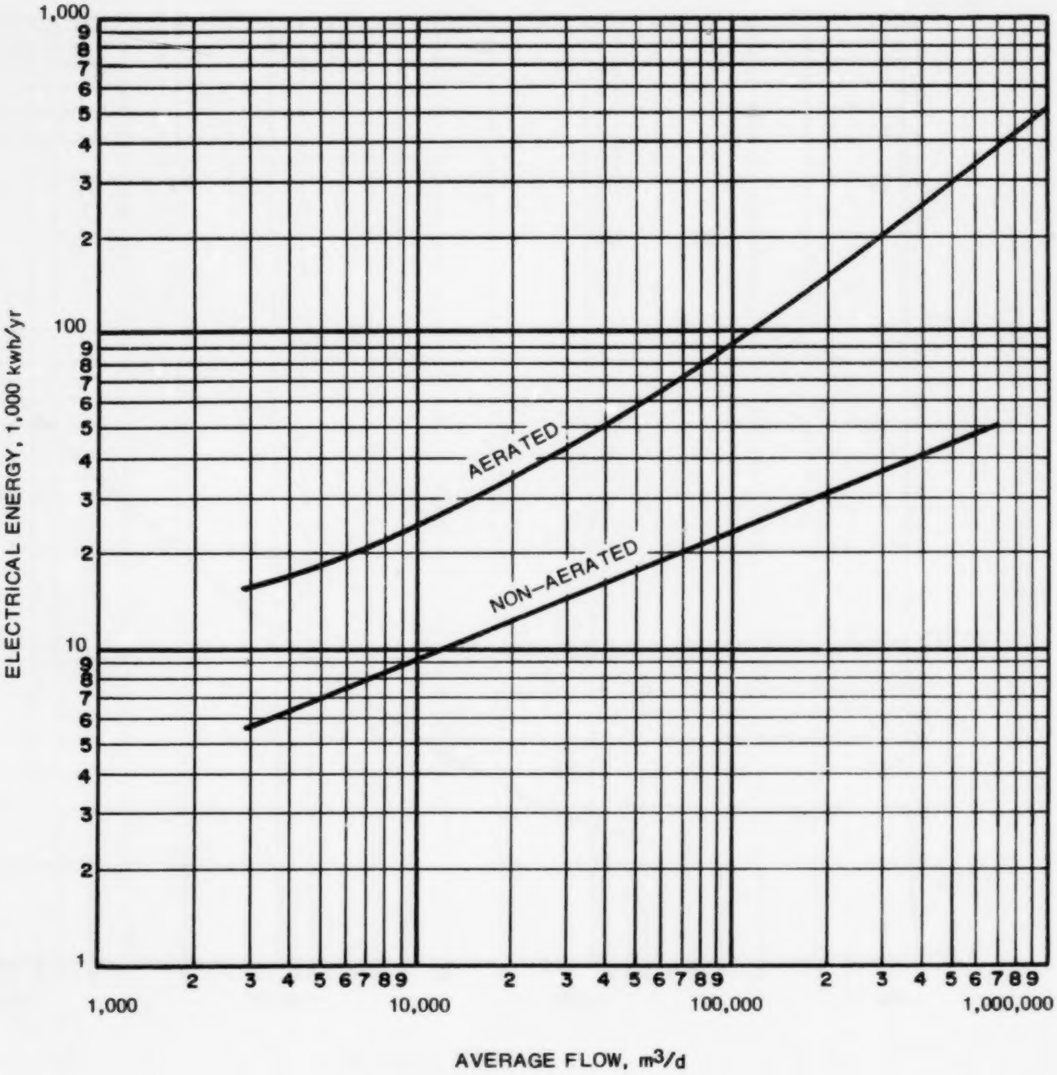


Figure OM5. Energy requirements for grit removal and flow measurement.

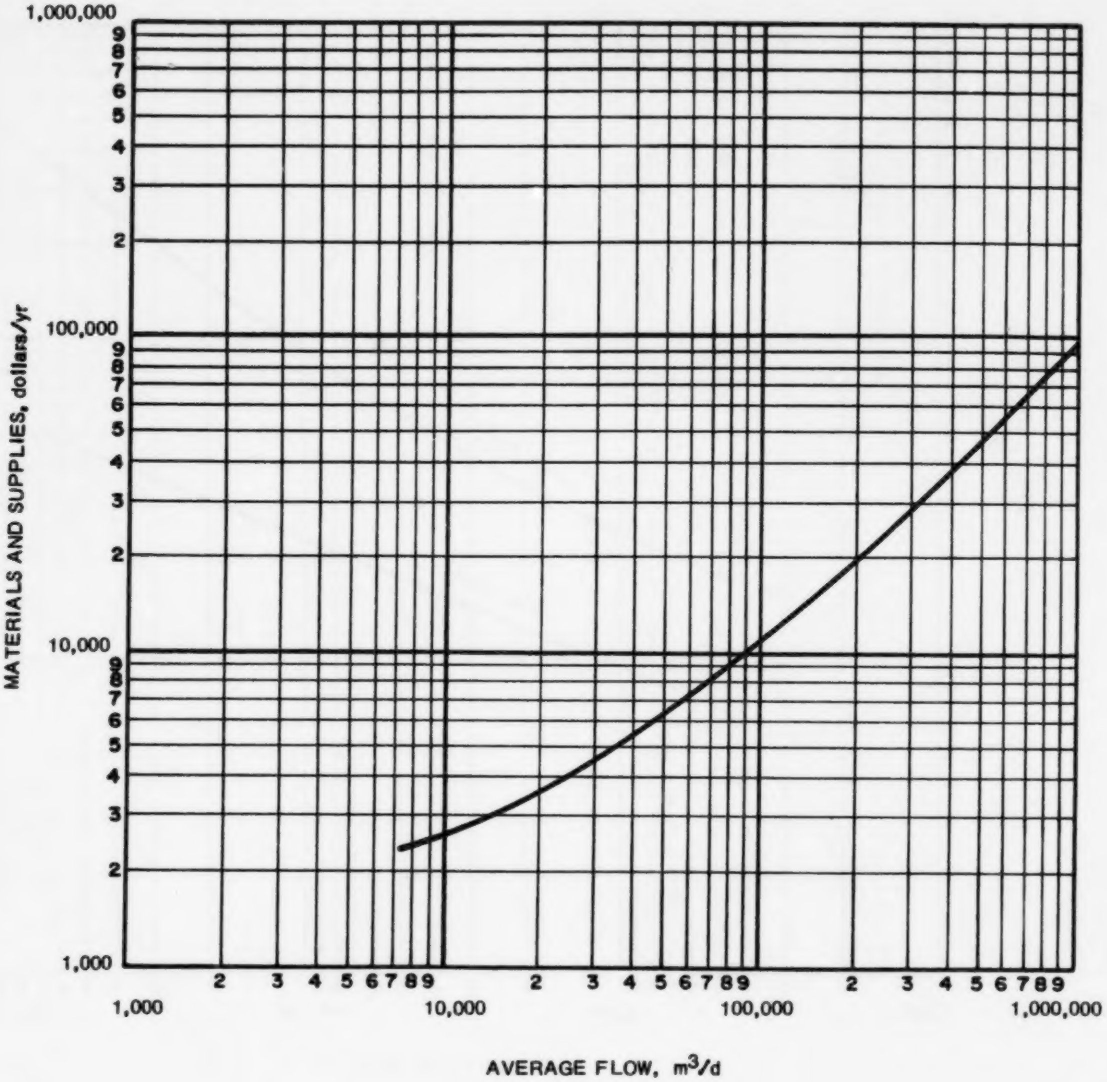


Figure OM6. Maintenance material and supply costs for grit removal and flow measurement.

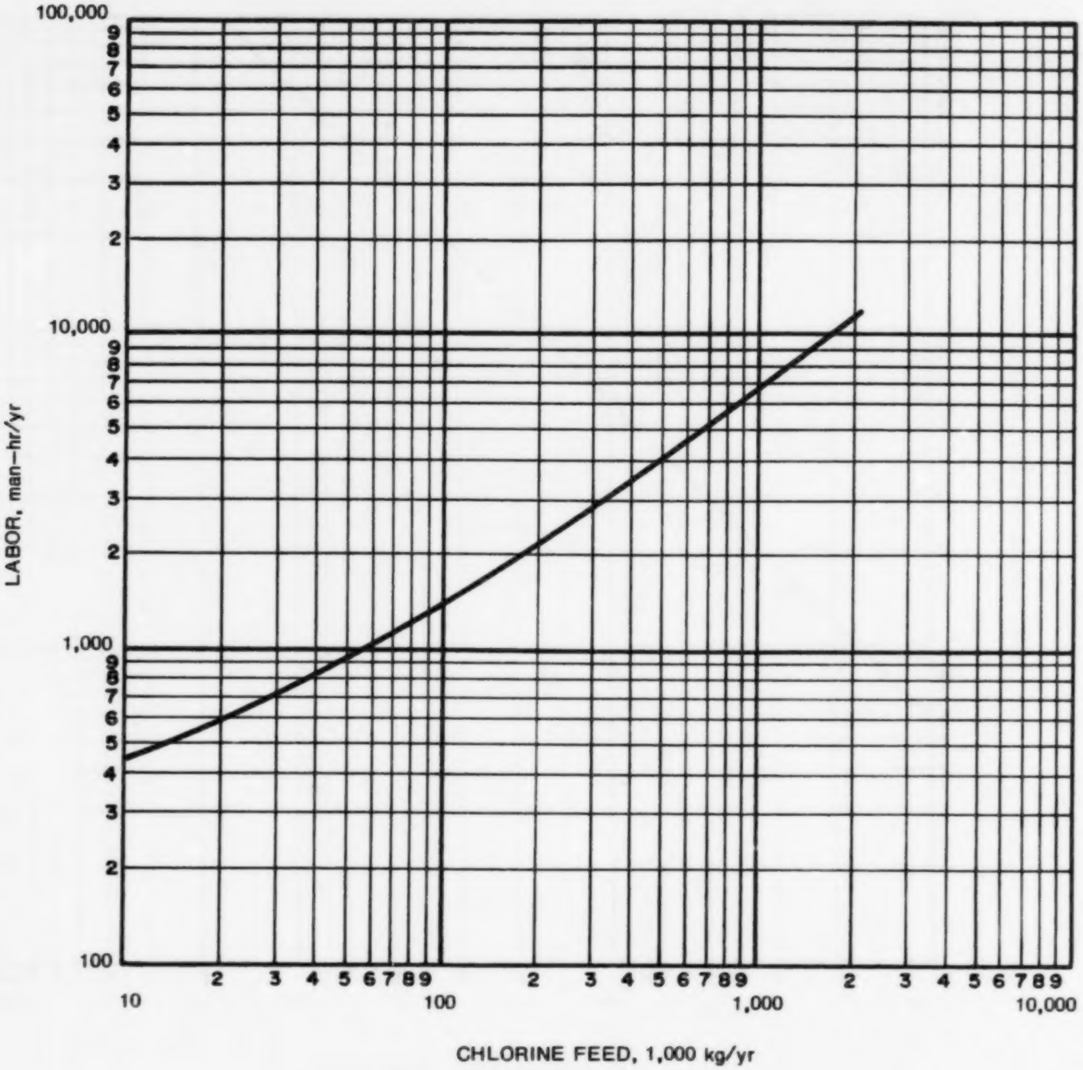


Figure OM7. Labor requirements for chlorination.

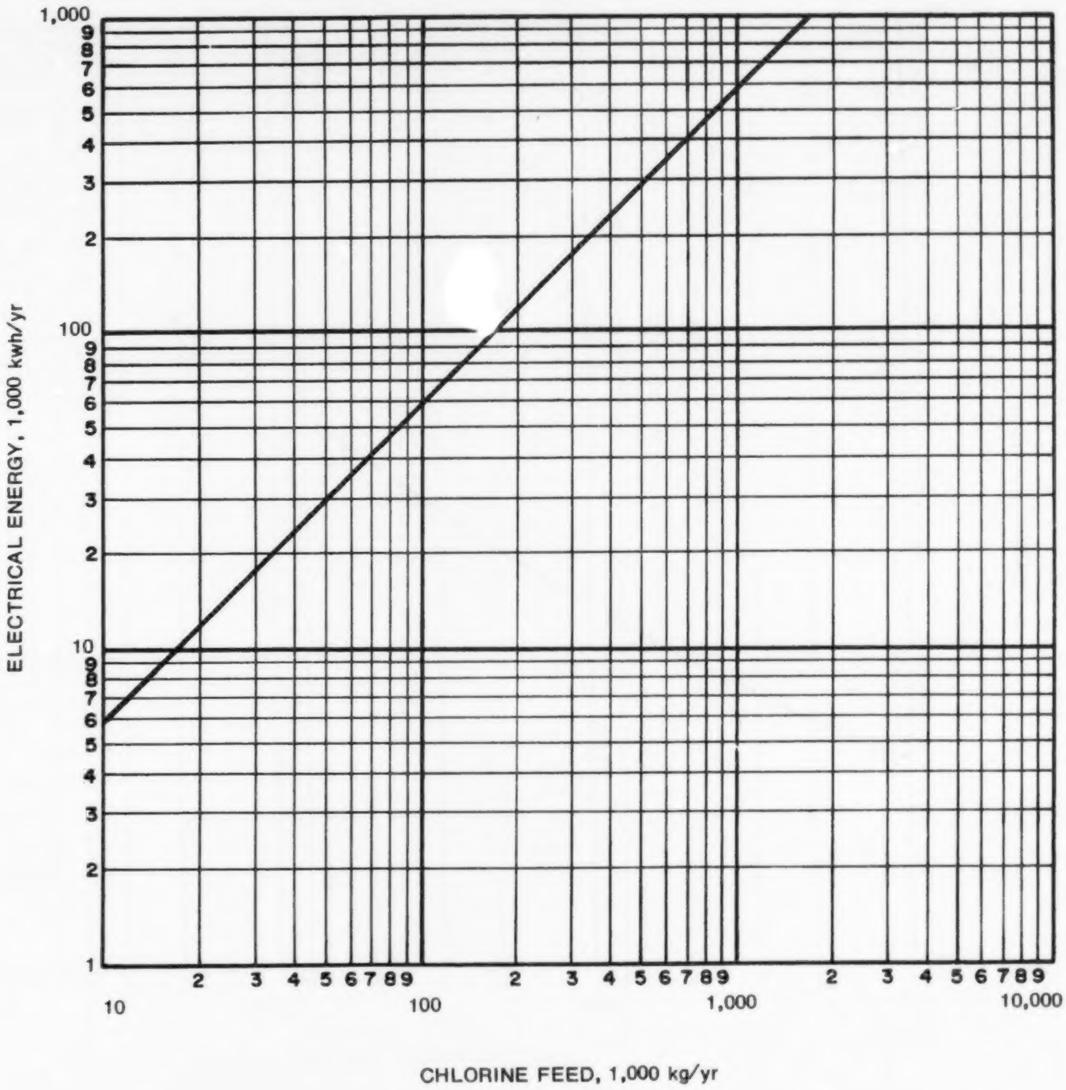


Figure OM8. Energy requirements for chlorination.

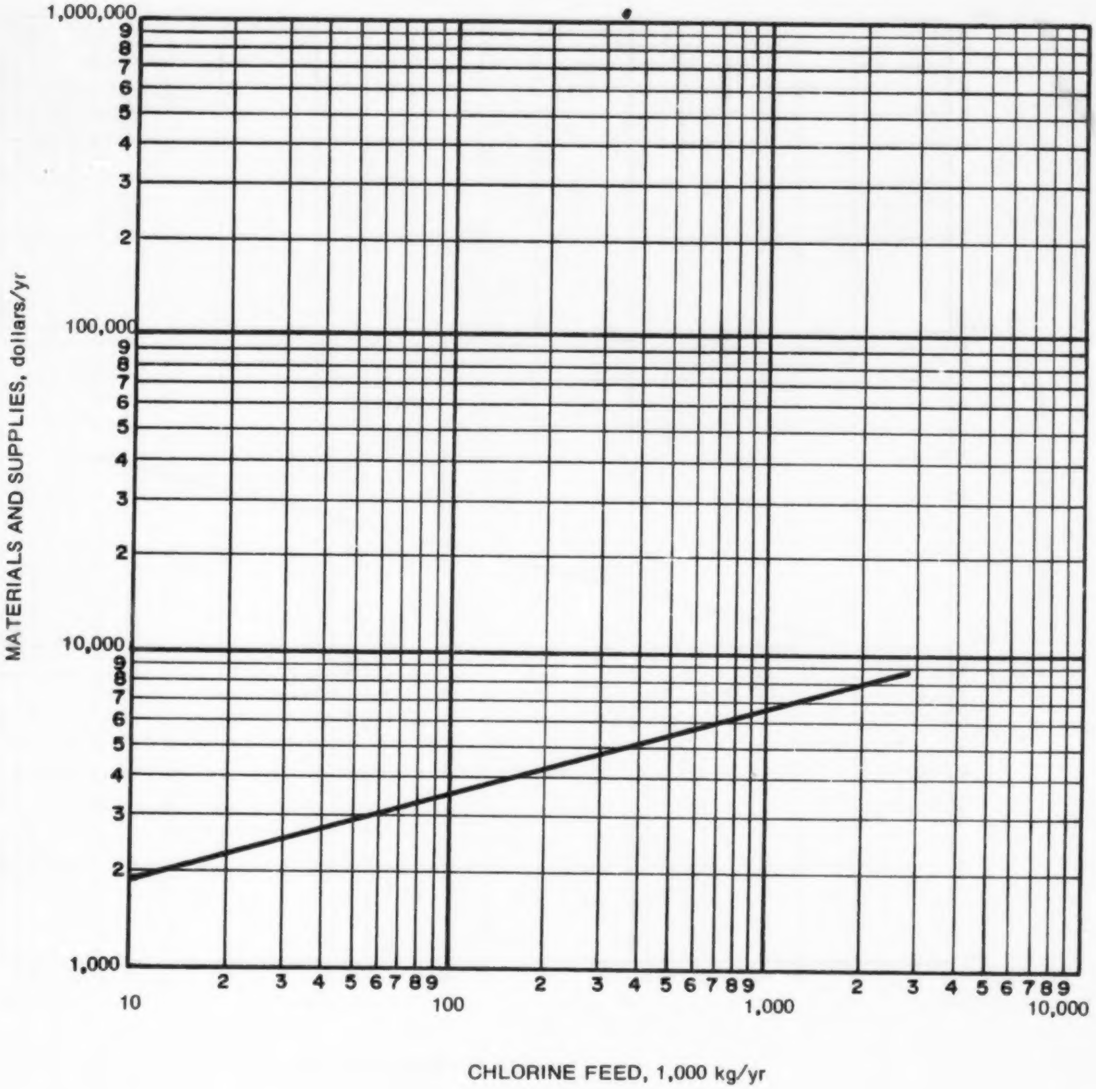


Figure OM9. Maintenance material and supply costs for chlorination.

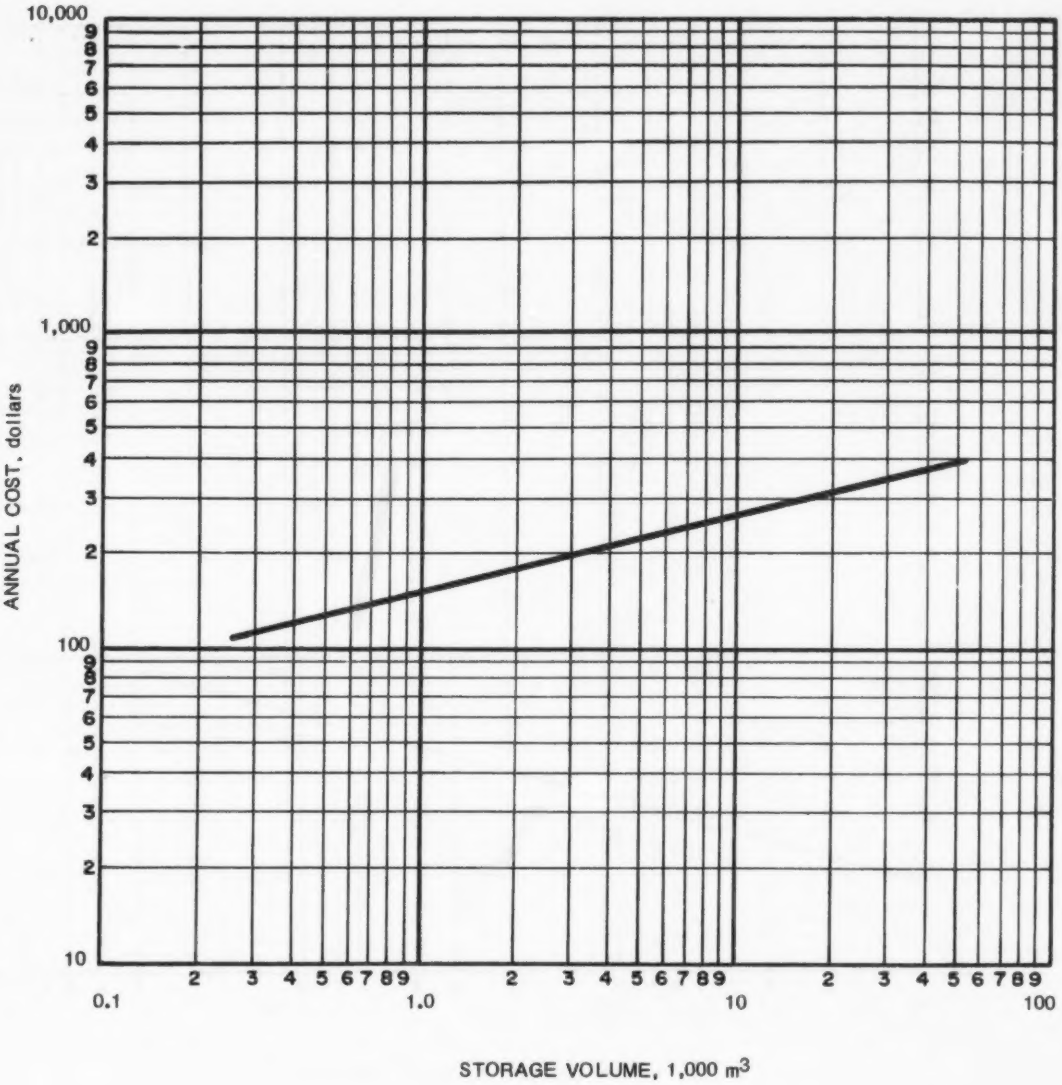


Figure OM10. Maintenance materials and supply costs for storage reservoirs. (100-100,000 m^3)

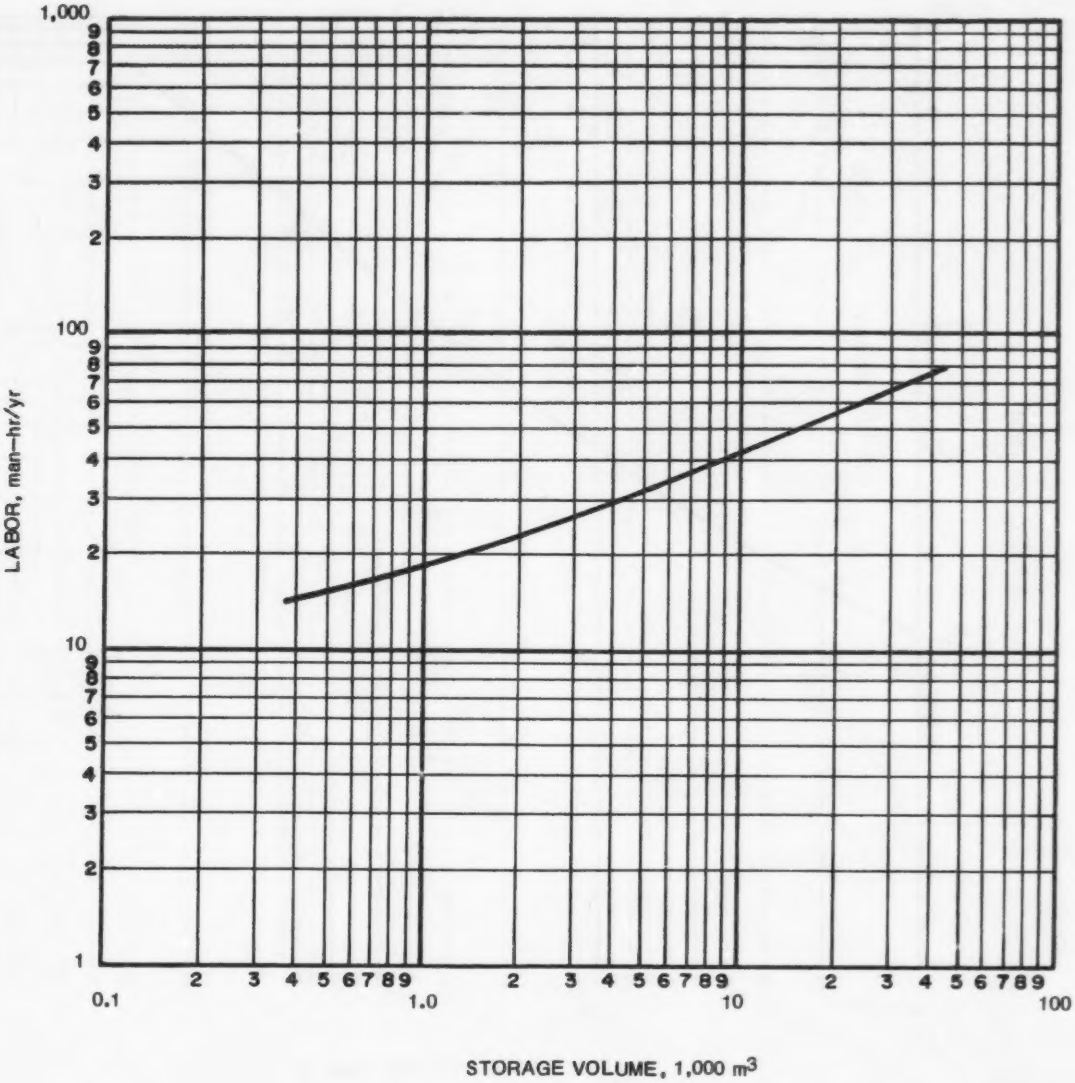


Figure OM11. Labor requirements for storage reservoirs. (100-100,000 m^3)

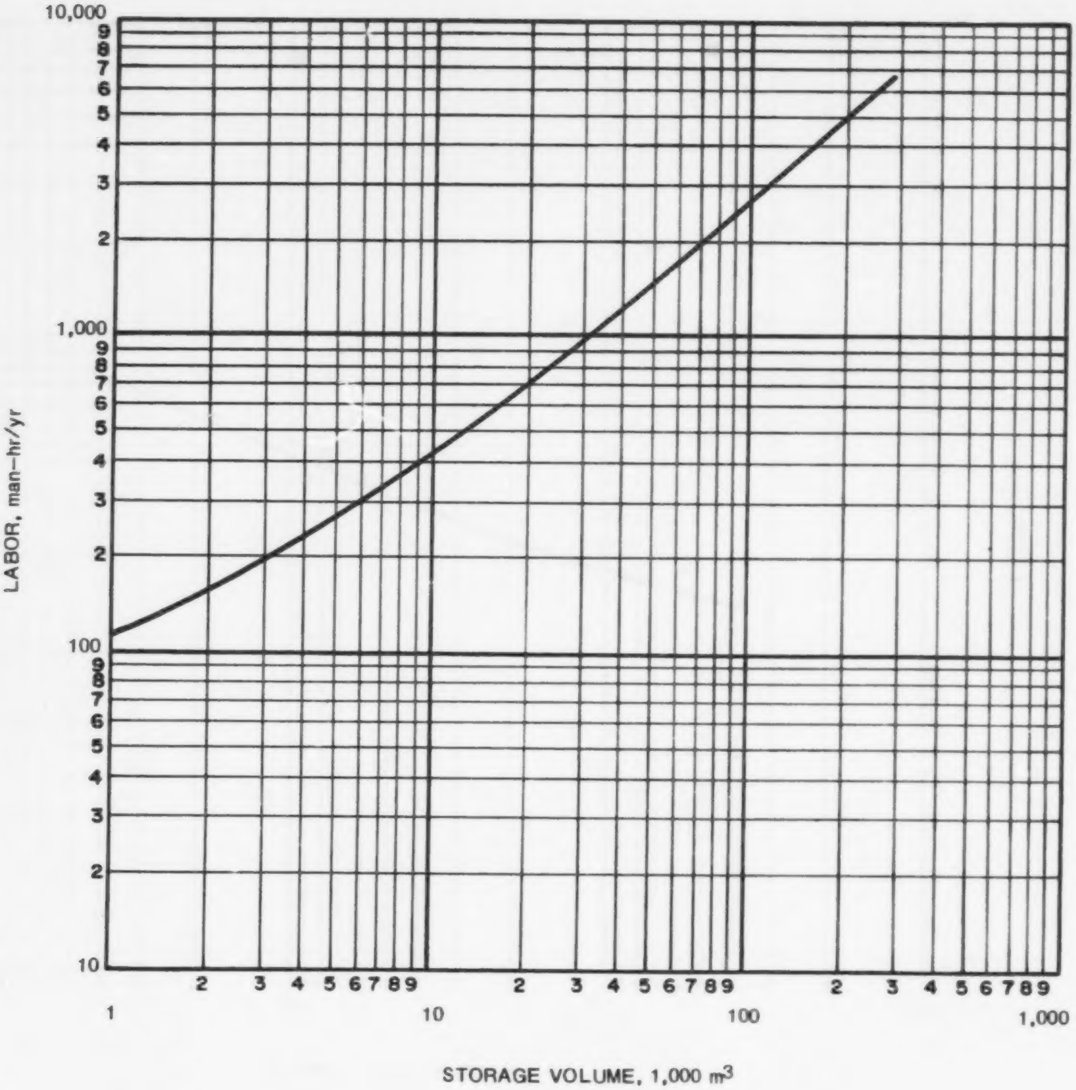


Figure OM12. Labor requirements for storage reservoirs. (5m water depth)

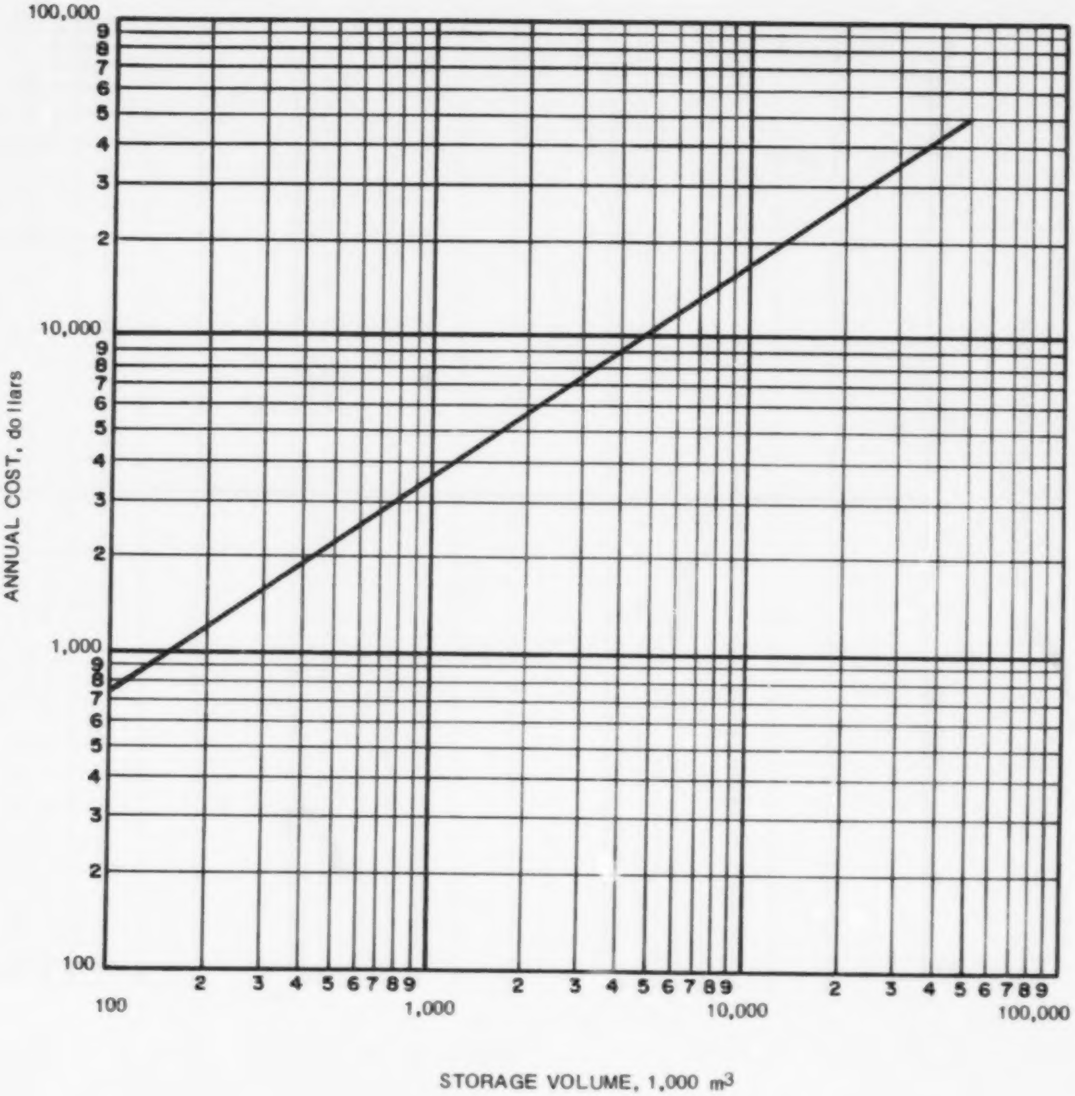


Figure OM13. Maintenance material and supply costs for storage reservoirs. (100,000-100,000,000 m^3)

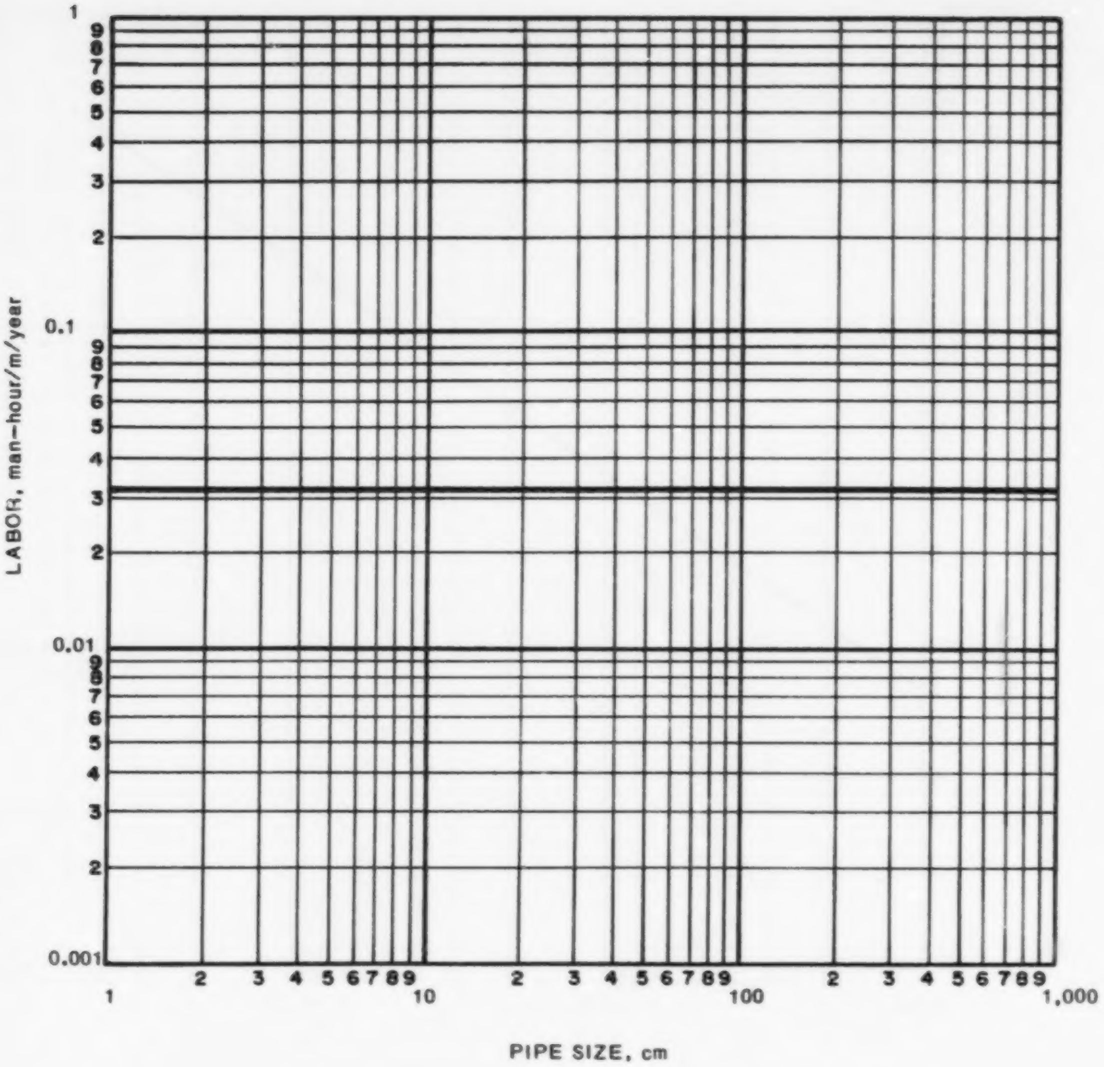


Figure OM14. Labor requirements for forcemains.

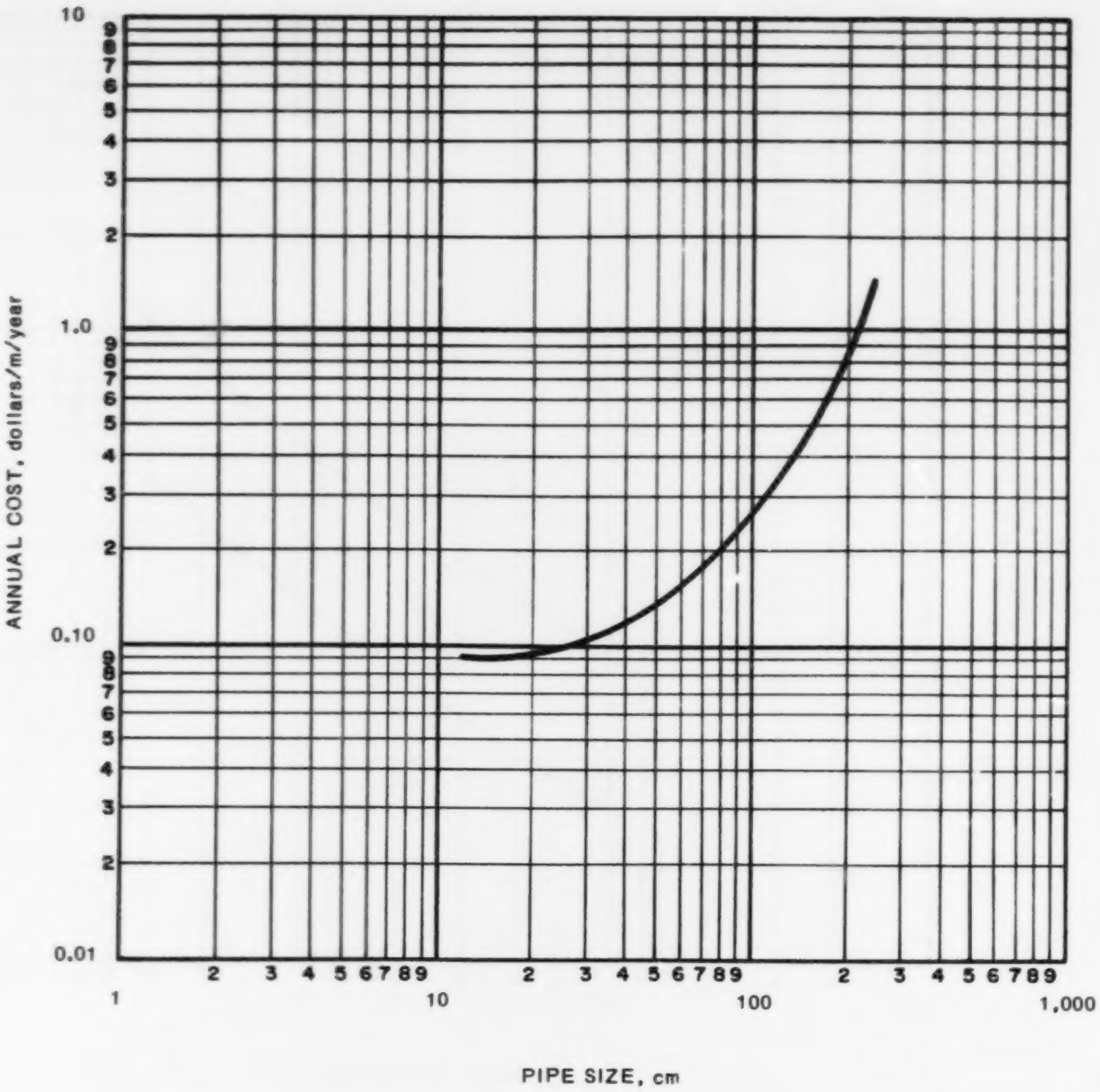


Figure OM15. Maintenance materials and supplies cost for forcemains.

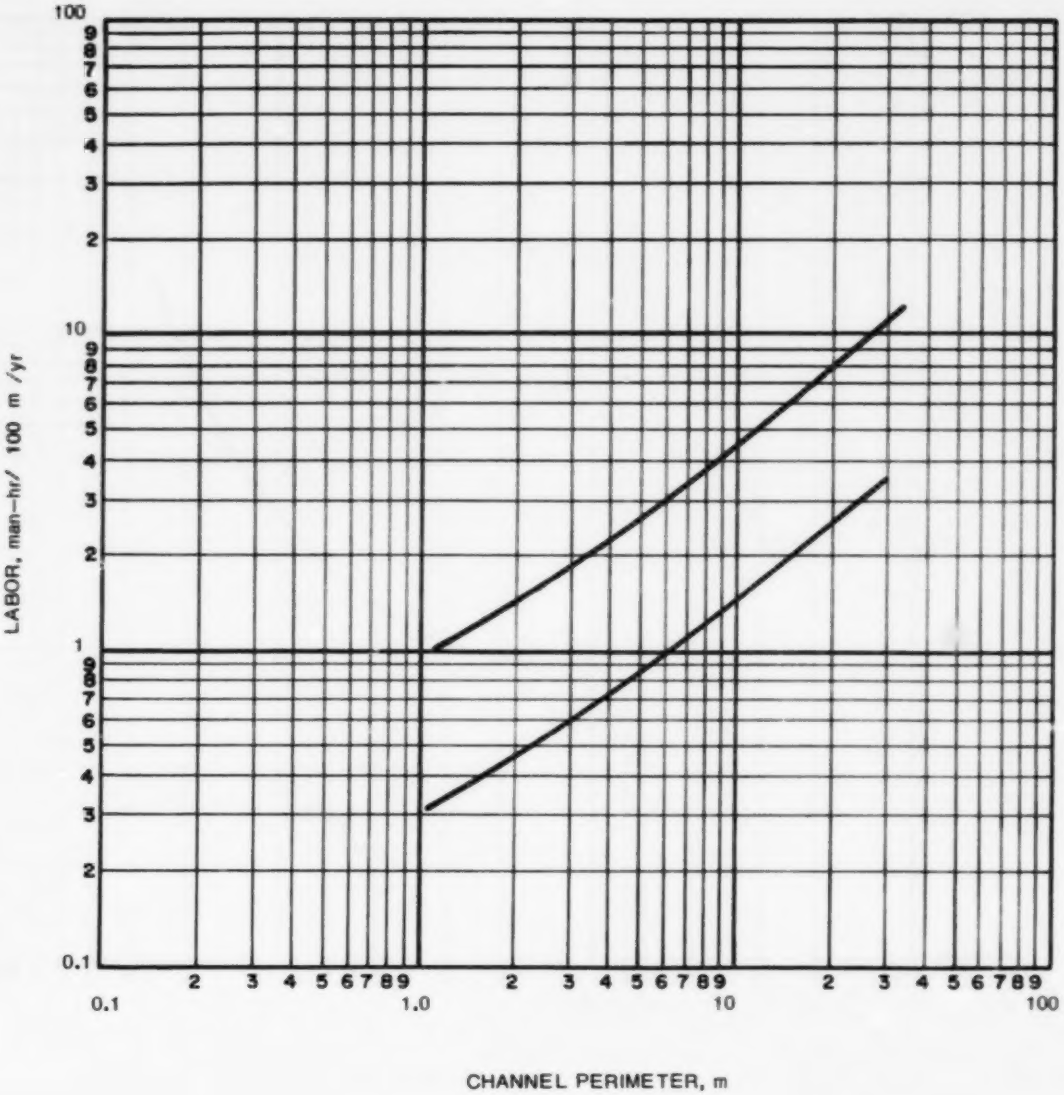


Figure OM16. Labor requirements for lined channels.

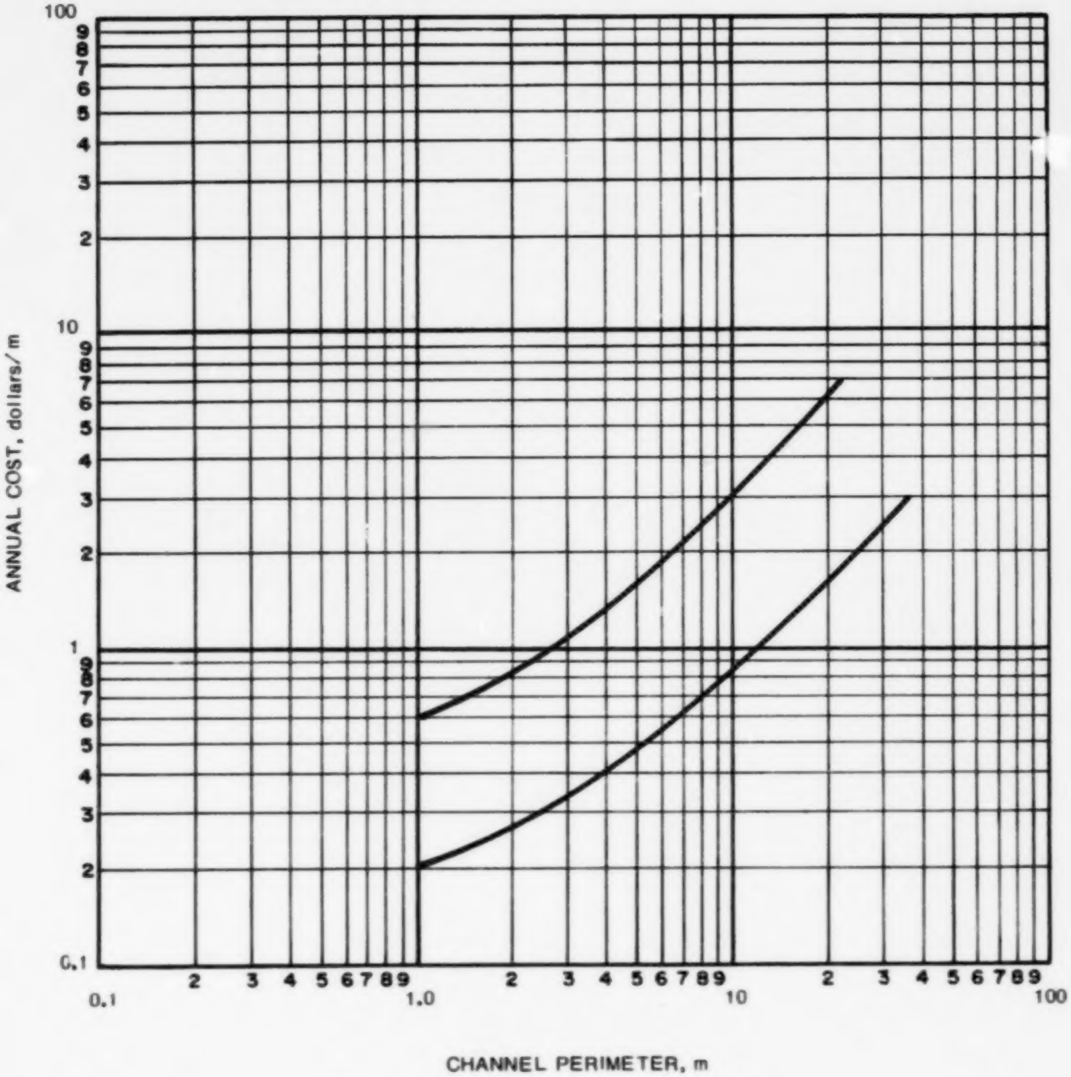


Figure OM17. Maintenance materials and supply costs for lined channels.

APPENDIX B

STATE OF MARYLAND

DESIGN GUIDE FOR LAND TREATMENT

(Sections Dealing with Overland Flow)

FOREWARD

In recognition of the needs for public health protection and water resource conservation, Maryland State Environmental Health Administration is adopting Technical Bulletin, M-DHMH-EHA-S-003, as design guidelines for land application of domestic wastewater.

The prime purpose of this publication is to assist planners in scheduling community development and to assist engineers in preparing plans and specifications. So long as public health is protected and discharge effluent limitations are met, application of the guidelines should be flexible to suit the practical needs of local conditions. With substantive and adequate evidence and subsequent approval by the Environmental Health Administration's technical staff, design details may deviate from the guidelines established.

This technical bulletin has been reviewed by a Technical Panel consisting of 14 members which represent the State Environmental Health Administration, the Water Resources Administration, County officials, the Washington Suburban Sanitary Commission and consulting firms.

These guidelines are subject to future modifications and revisions based upon further operational experience of land application systems. All users are encouraged to submit suggested revisions and pertinent information to the Division of Design Review, Environmental Health Administration, 201 West Preston Street, Baltimore, Maryland 21201.

Original Signed
Donald H. Noren, Director
Environmental Health Administration

October 24, 1978
Effective Data

CHAPTER I - INTRODUCTION

Land treatment or land application is the treatment of wastewater by using plant cover, soil surface, soil profile, and geologic materials to remove certain wastewater pollutants.

Land treatment of municipal wastewater encompasses a wide variety of processes or methods. The three principal processes are: (1) Slow Rate (Spray Irrigation), (2) Rapid Infiltration, and (3) Overland Flow. Other processes, which are less widely used, include: (1) Wetlands, (2) Subsurface, and (3) Bermed Infiltration Ponds.

1.3. Overland Flow

In overland flow wastewater is applied over the upper reaches of sloped terraces and allowed to flow across the vegetated surface to runoff collection ditches, usually for subsequent surface discharge. The pollutants are removed by physical, chemical, and biological means as it flows in a thin film down a relatively impermeable slope.

CHAPTER II - SITE SELECTION

2.1. Administrative Procedures

When a site is proposed for land treatment, the administrative procedures to be followed are:

1) A joint inspection shall be made by representatives of the Environmental Health Administration, the Water Resources Administration and local government in conjunction with the applicant and/or the applicant's authorized engineers to determine if the proposed site will be technically feasible for land treatment. Considerations are generally given to soil characteristics, topography, groundwater table and available buffer area provided at the proposed land application site.

2) Based on findings of the preliminary site evaluation, the applicant will be advised whether or not to retain a consultant to conduct a hydrogeological study and prepare a report.

3) The applicant shall submit an application to the Water Resources Administration for a groundwater or surface discharge permit.

4) The detailed hydrogeological report will be further evaluated by the Environmental Health Administration and the Water Resources Administration to determine the use of a suitable land treatment process and to recommend a practical rate of application.

5) Upon issuance of a discharge permit by the Water Resources Administration, the engineer retained by the applicant may proceed with the design of the selected system in accordance with guidelines established by the Environmental Health Administration.

6) Subsequent to a complete review of the design documents, the Environmental Health Administration will issue a construction permit for installation of the land treatment system.

2.2. Soil Characteristics

C. Overland Flow

Dense, well packed soils with limited or poor permeability such as heavy clays, clay soils, and soils underlain by impermeable lenses (fragipans) are required. A mantle of 6" to 8" of good top soil is recommended.

2.3. Topography

The land application site shall be properly planted, sodded, and/or adequately covered with vegetation except in rapid infiltration systems. The needs for vegetative cover are:

1) prevention of soil erosion,
2) elimination of direct surface runoff of wastewater applied (except for the overland flow process), and
3) enhancement of application rate and treatment.

The design shall also consider possible erosion and storm water runoff in the areas adjacent to the land application site.

C. Overland Flow

A sloping terrain is necessary to allow applied wastewater to flow slowly over the soil surface to the runoff collection system. Formed slopes of 2% to 8% will be required, with 2% to 6% preferred. The length of the slope generally ranges from 100 ft to 300 ft.

2.4. Groundwater

Investigation of groundwater at a prospective land application site must be conducted to evaluate the effect of groundwater levels on renovation capabilities as well as the effect of the applied wastewater rate on groundwater movement and quality.

C. Overland Flow

Groundwater depth is not critical in an overland flow system as the system is designed principally for runoff of applied effluent rather than percolation, but should not rise to root zone and interfere with plant growth or slope construction.

CHAPTER III - PREAPPLICATION TREATMENT, LOADING RATE AND CYCLE TIME

3.1. Preapplication Treatment

3.1.1. General

Prior to land treatment, the wastewater generated from domestic establishments shall be treated to a degree sufficient to accomplish the following goals:

1) To permit the effluent to be amenable to treatment by soils and to meet the discharge effluent limitations.

2) To prevent solids cloggings in the distribution system, and maintain a reliable system.

3) To provide effective disinfection, if disinfection is required.

In general, preliminary or primary treatment is required for overland flow, and secondary treatment is required for both rapid infiltration and slow rate. Guidelines and criteria for design of wastewater pretreatment facilities should conform to design guidelines set forth by the Maryland State Environmental Health Administration.

3.1.2. Disinfection

The purpose of disinfection is to destroy all pathogenic microorganisms and thereby prevent transmission of disease through the agency of air or water. Disinfection can be applied at any point in the treatment system.

Disinfection of pretreated wastewater must be accomplished if it is to be applied to land by the technique of spraying. Where flooding and/or ridge and furrow methods are used, disinfection may not be required. However, the site should be fenced to discourage trespassing.

When the proposed land application site is in an isolated area and effective measures for the prevention of human contact are taken, the Environmental Health Administration may determine that disinfection will not be necessary. However it should be emphasized that each site will be evaluated on a case-by-case basis.

3.2. Loading Rate

The hydraulic loading rate should not exceed the infiltration capacity of the soil except for an overland flow system and should be evaluated in accordance with the water balance principle delineated below.

$$\begin{array}{c}\text{Precipitation}\\ \text{rate}\end{array} + \begin{array}{c}\text{Hydraulic}\\ \text{loading rate}\end{array} = \begin{array}{c}\text{Evapotranspiration}\\ \text{rate}\end{array} + \begin{array}{c}\text{Percolation}\\ \text{rate of soil}\end{array} + \text{Runoff}$$

For an annual water balance, the following rates shall apply.

Where, (1) precipitation rate should be the annual rate of the wettest year in the past 10 years,
(2) evapotranspiration rate should be the annual average rate in the past 10 years, and
(3) runoff should be zero for slow rate and rapid infiltration.

In addition, a monthly water balance shall be prepared using appropriate monthly rates for each component system.

Where requirements for discharge to groundwater are very stringent for nitrogen, loading rate shall be adjusted to protect the groundwater against pollution from excessive nitrate.

C. Overland Flow

Hydraulic loading rates, when preliminary or primary effluent is applied, may range from 2.5 to 8 inches per week. Lower values of 3 to 4 inches per week should be observed for (1) slopes greater than 6%, (2) for terraces less than 150 feet, or (3) because of reduced biological activity during cold weather.

For secondary effluent, a maximum loading rate of 16 inches per week is recommended. Lower values of 7 to 10 inches per week should be observed when (1) to (3) described above apply. Application technique should be selected to minimize spray drift and preferrably should be surface application.

3.3. Cycle Time

The cycle time is defined as the period between two consecutive applications of pretreated wastewater on a specific site.

C. Overland Flow

Loading rates and cycles for an overland flow system are designed to maintain active microorganism growth in grass litter and on the soil surface. Optimum application times generally are 6 to 9 hours daily during 5 to 7 days a week. Application cycles may be extended during warm weather.

CHAPTER IV - STORAGE

4.1. General

Storage capacity for treated wastewater shall be provided since land disposal facilities are not designed to handle the surge flow or to operate during inclement weather periods.

4.2. Storage Capacity

Storage capacity depends upon wastewater flow, land treatment technique, storage period, direct rainfall, etc. It shall be adequate to hold treated wastewater for at least 60 days and to store any direct precipitation during the inclement weather periods of a wet season.

4.3. Lining

The bottom of storage ponds shall be lined with impervious material to prevent leakage and to preserve effective storage capacity especially during the wet season when the groundwater table is high. Underdrainage shall be provided where groundwater levels or pressures affect the lining or foundation of storage ponds.

4.4. Screening Device

Screening devices shall be installed at the outlets of storage ponds to remove solids and floating debris to protect downstream facilities against plugging. Procedures must be established to inspect and to clean screening devices on a routine basis.

4.5. Fence and Warning Signs

Storage ponds should be in fenced areas to keep the public from trespassing, fishing, or swimming. Fences should be at least 6 feet high and fence gates should be equipped with chains and locks. Warning signs should be posted at proper locations to keep the public from trespassing the premises and from engaging in fishing or swimming activities.

4.6. Storage Pond Bypass

A bypass around the storage ponds shall be constructed to permit pretreated effluent to flow directly from the pretreatment process to the site where facilities are available for land application. Bypass lines between the pretreatment process and storage ponds shall be properly valved to facilitate flexible operations of the land application system.

4.7. Aeration Facilities

Aeration equipment may be required in storage ponds for one or both of the following purposes:

1) To minimize effects of ponds' turnover during freezing and thawing cycles.
2) To provide supplemental oxygen for protection against odors when storing primarily treated wastewater.

CHAPTER V - SURFACE DRAINAGE SYSTEM, BUFFER ZONE AND LAND REQUIREMENT

5.1. Surface Drainage System

Surface drainage systems should be designed to collect surface run-off resulting from precipitation on land application sites. Surface drainage systems should be sized for a 10-year storm recurrence interval, but should also be capable of withstanding hydraulic erosion.

Run-off entering surface drainage system should be channelled through an online sediment collection basin and connected to a storm drain system. Deposits of grit, debris, etc., collected in the basin should be removed periodically so as to maintain required sediment capacity.

5.2. Buffer Zone

Where wastewater is applied to the land via spraying, a 200-foot minimum buffer area is recommended from the wetted perimeter of the spray field to property lines, streams, public roads, etc. Where spray fields are located in areas adjacent to housing developments, a 500-foot buffer zone is desirable. However, variance to these restrictions may be considered where it can be demonstrated that an adequate windbreak or other techniques are provided to prevent spray from going beyond the boundaries of land treatment site.

Where spraying is not a method of distribution, a 50-foot minimum buffer area is recommended from the boundaries of wetted basins to property lines, streams, public roads, etc.

5.3. Land Requirement

The total land requirement associated with a given land application project shall include the following areas.

C. Overland Flow

Data available from overland flow treatment of municipal wastewater consists of experimental and pilot study results. Evaluation of these data suggest the following for design of such systems.

To achieve a nitrified effluent: calculate similarly to slow rate systems except that the hydraulic application rate shall be taken as that for warm weather rates plus 25% land allowance for grass management.

1) Irrigation field (sized according to the weekly average application rate).

Wetted Field Area (acrea) $= Q \times \frac{257}{A} \times \frac{365}{365-T}$

Q = average daily flow in mgd
A = hydraulic loading rate in inches per week
T = lagoon storage period in days

2) Storage ponds (discussed in Section 4.2).

3) Buffer zone (discussed in Section 5.2).

4) Installation of sewage treatment facilities, and accessories.

5) Future expansion if desired.

6) An additional 25% of land above the wetted field area be reserved in case the application rate needs to be adjusted after the system is in operation. This extra 25% of land may be used for future expansion, if the system is achieving the desired effluent quality limitation at the design rate.

To achieve a denitrified effluent: calculate similarly to slow rate systems except that the hydraulic application rate shall be taken as that for winter weather rates.

CHAPTER VI - PUMPING STATION

6.1. General

Pumping stations for delivering wastewater to land application sites should be designed according to the "Design Guidelines for Sewerage Facilities", Technical Bulletin: M-DHMH-EHA-S-001, Published by the Environmental Health Administration, Maryland State Department of Health and Mental Hygiene. However, special consideration should be given to these items specified in the following sections of this chapter.

6.2. Number of Pumps and Pump Capacity

One standby pump must be provided and available for service at all times. The capacity of the pumps excluding the standby unit shall not exceed the maximum permissible hydraulic loading rate on the designated area for one-day operation, and shall not be less than the theoretical pumping rate calculated on the basis of the following equation.

$$P = Q \times \frac{365}{(365-T} \times \frac{24}{H}$$

P = Pumping rate in "gpm"
Q = Average daily flow in "gpm"
T = Non-operating period in "day"

Non-operating period for a spray irrigation system should include those days when the system is shut down due to freezing temperature, high wind velocity, high intensity of rainfall, and crop harvesting if any.

H = Operation period in "hours per day"

For crop consumption and management, pumping-rate design will be determined accordingly.

6.3. Intakes from reservoirs or lagoons

Each pump shall have an individual intake with a screening device described in Section 4.4. Intakes should be designed to avoid turbulence and should be capable of drawing treated sewage at various elevations as desired by field operator.

6.4. Valves

Suitable shut-off valves shall be placed on suction lines and discharge lines of each pump system. A check valve shall be placed in discharge lines between shut-off valves and pumps. Selection of check valves should consider water-hammer effect.

6.5. Flow Measurement

A flow meter with recorder and totalizer shall be installed to measure flows pumped to the land application field.

6.6. Pump Removal

Provisions shall be made to facilitate removing pumps and motors for maintenance purposes.

6.7. Alarm System

An alarm system should be provided for pumping stations and telemetered to the area where 24-hour attendance is available. If 24-hour attendance is not available, an audio-visual device shall be installed at the station for external observation.

CHAPTER VII - DISTRIBUTION SYSTEM

7.1. General

The two distribution techniques generally used for land treatment are surface application and sprinkler application.

Surface distribution employs flow from piping systems or open ditches to flood the application area.

Sprinkler distribution, which simulates rainfall, may be of the permanent set or movable type.

7.2. Piping Systems

Piping shall be arranged to provide flexibility for expansion, modification, inter-connection, and partial isolation.

7.2.1. Pressure Control

Lateral lengths and pipe sizes shall be selected properly so that pressures along laterals will not vary more than 20%. Devices for regulating the pressure through distribution systems are required to maintain uniform discharge rates and uniform pressures if pressure is beyond this range. Employment of high pressure class pipes or installation of devices to delay valve closing times in distribution systems is recommended to prevent pipe failure due to high pressure surges.

7.2.2. Drain System

Drain valves shall be located at low points and at the end of each lateral to allow water to drain and prevent in-line freezing. Drainage shall be returned to the storage facility or discharged properly in gravel pits within the land application field.

7.2.3. System Protection

Where a buried system is utilized, proper buttresses at bends of the system shall be installed. To protect against freezing the frost line of the area should be considered before design. In general, laterals should be buried deeper than 2.0 feet and mains should have a minimum cover of 3.0 feet.

For above-ground systems, mains and laterals shall be anchored properly.

7.3. Solid Set Sprinklers

7.3.1. Risers

Sprinklers shall be elevated on risers high enough to ensure uniform distribution with the lowest possible trajectory. Risers shall be adequately supported to prevent damage from vibration and should have sufficient height to clear crops. Usually 3 to 4 feet of riser is used for a grass field.

7.3.2. Spacing

For uniform application, sprinklers need to be spaced properly so their distribution areas overlap. In general, the distance between sprinkler heads on laterals should not exceed 0.5 of the distribution area diameter; the distance between laterals should not exceed 0.65 of the distribution area diameter. Lateral spacings should be reduced where high wind velocities occur frequently.

7.3.3. Discharge Pressure

Discharge pressures at the sprinkler nozzles should be selected properly so that a uniform distribution of effluent over the distribution area can be expected. Typical nozzle discharge pressures generally range from 50 to 60 psi. The use of non-obstructive pressure regulators is recommended.

7.3.4. Distribution Area Diameter

The distribution area diameter shall be selected to allow even distribution. Large distribution area diameters usually involve high trajectories resulting in greater distortion of the distribution pattern, especially during excessively high winds.

The diameter shall not exceed 140 feet on any type of application. Generally, smaller diameters are desirable in wooded and steeper slope areas.

7.5. Surface Application Systems

Surface flooding systems should be designed to apply pre-treated wastewater at a rate which will constantly flood the field in use at a relatively uniform depth. Care must be taken to minimize erosion at the point of application. This method of distribution is used mainly for rapid infiltration systems. Surface distribution methods include ridge and furrow irrigation, surface flooding irrigation, bubbling orifices and gated surface pipe.

7.5.3. Bubbling Orifices

Bubbling orifices are small diameter outlets from laterals used to introduce flow to overland flow systems. These outlets may be orifices in the laterals or small diameter pipe stubs attached to the laterals.

7.5.4. Gated Surface Pipe

Gated surface pipe denotes a pipe with multiple outlets. The pipe can be attached to hydrants fixed to valved risers. Slide-gated or screw-adjustable orifices must be provided at each outlet to control the flow.

CHAPTER VIII - MONITORING

8.1. General

As with any wastewater treatment facility, a comprehensive monitoring program will be required to ensure that proper renovation of wastewater is occuring and that environmental degradation is not taking place.

8.2. Renovated Water

The monitoring of renovated water may be required for either groundwater, or recovered water, or both. Recovered water is the runoff from overland flow, or water from recovery wells, or underdrains if used.

Water quality parameters that should be analyzed in groundwater and renovated water include those that are required by the discharge permit and those that are necessary for system control.

8.4. Soils

In almost all cases, the application of wastewater to land will result in some changes in the characteristics of the soil. Consequently, a soil monitoring program will be helpful for most systems.

8.4.1. Levels of Various Chemical Elements

The long-term build-up of various elements to unacceptable levels in the application site should be evaluated. One area of major concern in many cases is the Sodium Adsorption Ratio (SAR). High values may adversely affect the permeability of soil. The formula for evaluation of Sodium Adsorption Ratio is shown as follows:

$$SAR = \cfrac{Na^{+}}{\cfrac{Ca^{++} + Mg^{++} \ 1/2}{2}}$$

where Na^{+} = Sodium ion concentration in milliequivalents per liter of water
Ca^{++} = Calcium ion concentration in milliequivalents per liter of water
Mg^{++} = Magnesium ion concentration in milliequivalents per liter of water

The Sodium Adsorption Ratio should be maintained below 9 to prevent the dispersion of clay to avoid the sealing of the soil. Sodium Adsorption Ratio can be reduced by adding Calcium ions or Magnesium ions, such as gypsum, into the water.

CHAPTER IX - CROP MANAGEMENT

9.1. General

Because the renovation of wastewater is dependent in part upon crops and vegetation (except in rapid infiltration systems), consultants must develop a crop management program at the design stage. Assistance in design and planning can be provided by the U.S. Department of Agriculture, Soil Conservation Service, and local farm advisers. Detailed procedure should be programmed in conjunction with the design of land application systems.

9.2. Crop Selection

Factors which influence crop selection are nutrient removal efficiency, suitability to the climate, soil, and wastewater applications, and tolerance to wastewater constituents. The four general classes of crops that may be considered are: (i) Annuals, (ii) Perennials, (iii) Landscape vegetation and, (iv) Forest vegetation.

9.3. Cultivation and Harvesting

For the simple operation of systems, ease of cultivation and harvesting of selected crops is important.

It is critical to maintain soil vegetation systems in healthy, productive and renovative states. This involves regular harvesting and cutting of grass crops and vegetation, adequate drying periods after application, and care in operating farm machinery which may cause excessive soil compaction.

REFERENCES

1. CH2M Hill, Design Seminar for Land Treatment of Municipal Wastewater Effluents - Design Factors Part II, Prepared for United States Environmental Protection Agency Technology Transfer Program. (September 1975).

2. Foster, H. B., Jr., Ward, Paul C., and Prucha, Arnold A., "The Removal of Nutrients by Spraying Effluent on a Saturated Hillside - Lake Tahoe, California". Staff Report, Bureau of Sanitary Engineering, California State Department of Public Health (May 1975).

3. Great Lakes - Upper Mississippi River Board of State Sanitary Engineers, Recommended Standards for Sewage Works (Ten States Standards). (1973).

4. Lappo, Richard L., "Living Filter, Perks up Regional Sysem". Water and Wastes Engineer, P. 18, (June 1976).

5. Metcalf & Eddy, Inc., Design Seminar for Land Treatment of Municipal Wastewater Effluents - Design Factors Part I, Prepared for United States Environmental Protection Agency Technology Transfer Program. (August 1975).

6. Metcalf & Eddy, Inc., Wastewater Engineering - Collection, Treatment and Disposal, McGraw-Hill Book Company (1972).

7. Pennsylvania Department of Environmental Resources, Spray Irrigation Manual, Publication No. 31, Bureau of Water Quality Management, Harrisburg, Pennsylvania (1972).

8. U.S. Department of Agriculture, Conservation Irrigation in Humid Areas, Agriculture Handbook 107 - Soil Conservation Service (January 1957).

9. U.S. Environmental Protection Agency, Evaluation of Land Application Systems, Technical Bulletin - EPA - 430/9-75-001 (March 1975).

10. U.S. Environmental Protection Agency, Land Application of Wastewater in Australia, Technical Bulletin - EPA - 430/9-75-017 (May 1975).

11. U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, U.S. Department of Agriculture, Process Design Manual for Land Treatment of Municipal Wastewater, Technical Bulletin - EPA - 6215/1-77-008 (October 1977).

12. Metcalf & Eddy-Sheaffer & Roland, Preliminary Assessment Feasibility of Land Treatment of Wastewater in Prince George's County, Maryland, prepared for the Washington Suburban Sanitary Commission. (Draft copy, June 1977).

13. Oklahoma State Department of Health, Design "Guidelines for Land Application of Municipal Wastewater."

14. The Irrigation Association, Wastewater Resource Manual, June 1977.

15. Thomas K. Jackson, L. Penrod, "Feasibility of Overland Flow Treatment of Raw Domestic Wastewater". Robert S. Kerr, Environmental Research Lab - EPA - 660/2-74-087 (July 1974).

16. R. Thomas, B. Bledsoe, K. Jackson, "Overland Flow Treatment of Raw Wastewater with Enhanced Phosphorus Removal". Robert S. Kerr, Environmental Research Lab - EPA - 600/2-76-131 (June 1976).

APPENDIX C

STATE OF MISSISSIPPI

DESIGN GUIDE FOR LAND TREATMENT SYSTEMS
MISSISSIPPI AIR AND WATER POLUTION CONTROL COMMISSION

FINAL DRAFT

DESIGN GUIDANCE FOR LAND TREATMENT SYSTEMS
MISSISSIPPI AIR AND WATER POLLUTION CONTROL COMMISSION

May, 1979

I. Overland Flow Land Treatment Systems

A. Preapplication Treatment - Preapplication treatment will be provided to remove grit, large settable solids and to reduce the potential for odor problems at the site. Generally, treatment may be most effectively and economically provided in a new or existing lagoon. If a lagoon system is proposed, it should be designed with a 50 lb/day/acre organic loading based on BOD_5 with a minimum three (3) foot operating depth. A short detention time aerated lagoon should be given due consideration when a lagoon does not already exist. Also, aerators may be added to an existing lagoon, which provides adequate storage, to eliminate odor problems. The design engineer should remember that the purpose of the system is to provide storage and preapplication treatment.

B. Storage - A total effective storage of 30 to 60 days above that required for treatment is recommended. Storage volume may be provided in the pretreatment lagoon by regulating the depth above the three (3) foot operating depth. Short term storage of 10 to 15 days located "off-line" will be considered when it is demonstrated to be applicable to the project purpose and site conditions.

C. Preapplication Chlorination - If the method of application is designed and operated to minimize the production of aerosals, preapplication chlorination will not normally be required. This will be determined on a case-by-case basis depending on the application system proposed.

D. Hydraulic Loading Rate - The application rate on the site is to be a minimum of 2.5 inch/week for the yearly average over the entire application area. The hydraulic loading should be increased on a portion of the application area during the summer months to allow other areas to be dried and harvested. Greater loading rates shall be considered where local research and/or operating systems have demonstrated the capability and reliability in handling such loadings.

E. Distribution System - The utilization of a low head design is recommended whenever site conditions allow. This type of system lowers the O & M costs, may lower the capital cost and should minimize the production of aerosals. Gravity systems, gated pipe, bubble tube orifices or fixed fan nozzles are recommended for consideration.

F. Application Field Characteristics

1. Slope - Application slopes of 2% to 8% are recommended with consideration given to the existing topography to minimize the land forming requirements. The terraces should generally be 100 - 150 feet in length.

2. Soil Permeability - This may be measured by the falling head laboratory method or by other proven laboratory and/or field determination methods for overland flow systems. The permeability should be "slow" (Permeability of less than 0.2 inch/hour). The permeability may be greater than this value if an impermeable barrier appears in the soil profile between the soil surface and the ground water table.

3. Depth to Ground Water - This is not a critical consideration because this process is a surface treatment phenomenon. In-depth percolation must be inhibited by an impermeable layer in the soil profile above the ground water table.

G. Vegetative Cover - A vegetative cover is required for this system to provide nutrient uptake and protection from erosion. This vegetative cover should be capable of growing in a wet environment and have a higher nutrient uptake rate. Argentine byhalia, Reed Canary, and Coastal Bermuda should be considered with overseeding of rye grass in the winter.

H. Drainage/Collection System - A drainage system should be designed and constructed so as to eliminate rainfall runoff from flowing onto or off of the site. A collection system should be designed and constructed to collect all wastewater and rainfall runoff from the terraces and transport the flow to a single location for ultimate discharge to a surface stream. Multiple discharge points may be more appropriate and justifiable in some situations. These collection/drainage channels may be grassed ditches, tile or any material that will control erosion and facilitate maintenance. Any discharge must be to state waters.

I. Post Chlorination - The requirement for post chlorination (after treatment and prior to discharge to the receiving stream) will be assessed on a case-by-case basis. If required, chlorination would be provided for wastewater design flow only. Runoff above the design flow would bypass chlorination. All systems must meet the stream standards of 2000-4000 MPN/100 ml fecal coliforms as specified in the State of Mississippi Water Quality Criteria, adopted by the MAWPCC on April 12, 1977.

J. Buffer Zones - Buffer zones shall be provided around land treatment sites. The size of this border is dependent upon application method, proximity to dwellings, roads, land use, etc. Although the width of the buffer zone is negotiable, a value of 50 to 100 feet would seem to be adequate for most cases in which precautions have been taken to minimize spray drift and aerosals. Where possible, the application field should be built around the preapplication treatment and storage facility to provide the buffer for these units.

K. Public Access and Protection - This has been covered in buffer zones and chlorination practices. Public access to the site should be controlled through the use of fences and gates to restrict public access and to prevent livestock from entering the site. A 3 to 5 strand barb wire fence is recommended.

L. Monitoring

1. Groundwater - Contact MAWPCC for these requirements.

2. Discharge to Surface Stream - MAWPCC will issue an NPDES permit which will outline the frequency of sampling and parameters to be monitored in the influent and effluent.

II. Slow Rate Irrigation Land Treatment Systems

A. Preapplication Treatment - Generally provide a lagoon with a design organic loading of 50 lbs/acre/day BOD_5, using a three (3) foot operating depth. Secondary treatment before land application is not required. The preapplication treatment level will be directly related to the intended irrigation use of the wastewater. As the opportunity for public access increases, pretreatment requirements should be more stringent. A short detention time aerated lagoon should be given due consideration when a lagoon does not already exist. Also, aerators may be added to an existing lagoon, which provides adequate storage, to limit odor problems. The design engineer should remember that the purpose of the system is to provide storage and preapplication treatment.

B. Storage - Normally provide a minimum of 30 - 60 days of excess storage time above that provided in the pretreatment lagoon. Storage volume may be provided in the existing or proposed lagoon by varying the operating depth. Specific storage requirements are related to water balance. One system, such as a lagoon, could be used for both pretreatment and storage. Short term storage of 10 to 15 days located "off-line" will be considered when it is demonstrated to be applicable to the project purpose and site conditions.

C. Preapplication Chlorination - The requirement for chemical disinfection will be considered on a case-by-case basis. Extended storage prior to application may be effective in reducing fecal coliform levels to that which would be consistent with project objectives and requirements.

D. Hydraulic Loading Rate - A minimum application rate of 1.00 inch/week as a yearly average will be used. Loading rates of less than this value must be well supported and justified. A water and nutrient balance will be used to determine the specific application rate. Seasonal variations in hydraulic application should be considered to facilitate harvesting of crop by rotation of application areas. The recommended hydraulic loading rate and seasonal application schedule shall be supported by soils information specific for the project site and, as needed, on-site loading rate capacity determinations.

E. Application System - These may be fixed fan nozzles, traveling bridge sprinklers, impact sprinklers, or other high head systems, to facilitate even distribution of the wastewater over the application area. Where topography permits, ridge and furrow irrigation or flooding may be desirable.

F. Application Field Characteristics

1. Slope - Limit application area slopes to a maximum of 20% for cultivated land and 40% for noncultivated land. Consideration should be given to the potential for runoff and erosion.

2. Soil Permeability - A range of .2 to 0.6 inch/hour will be considered as an acceptable percolation rate.

3. Depth of Groundwater - Normally not less than 2 to 3 feet. If the groundwater depth is less than this value, an underdrain system should be considered to maintain the groundwater at a depth of 2 to 3 feet or more and to control groundwater mounding.

G. Vegetative Cover - Any crop not used for direct human consumption, or that is not fed directly to dairy cows, should be acceptable. Such crops would include corn, cotton, soybeans, green crop, etc. Truck crops or unprocessed vegetables (tomatoes, strawberries, etc.) shall not be irrigated in this manner. Irrigation of processed vegetables and/or fruits may be acceptable in some situations.

H. Drainage/Collection System - This system may not have a surface discharge during normal operation. All surface drainage and underdrain flow should be directed to controlled discharge points. Any discharge must be to State waters. Rain water falling outside the application site should be excluded from the site.

I. Post Chlorination - This should not normally be required because the system is generally designed not to have a surface discharge. A system designed to have a surface discharge must meet the stream standards of 2000-4000 MPN/100 ML fecal coliforms.

J. Buffer Zones - Buffer zones should be provided with a minimum width of 100 - 200 feet. Vegatative screens should be considered for use around the application site to minimize aerosal drift and wind effects. The buffer width would be directly related to the public access to the site and the type application system used. This will likely be determined on a case-by-case basis.

K. Public Access and Protection - Fencing may be needed around the entire application site to control livestock and to discourage trespassing. A 3 to 5 strand barb wire fence is recommended. Vegetative screens should be used to limit spray drift. Use of posting in conjunction with vegetative screens will be considered on a case-by-case basis for projects with appropriate objectives. Projects that are designed to have public access (golf courses, medians, parks, etc.) should not require these steps as long as access to the site is controlled during spray periods.

L. Monitoring

1. Groundwater - Contact MAWPCC for these requirements.

2. Discharge to Surface Stream - MAWPCC will issue an NPDES permit which will outline the frequency of sampling and the parameters to be monitored in both the influent and effluent on discharging

systems. Should the system be designed for zero discharge to surface water, a no-discharge State permit will be issued by the MAWPCC.

III. Rapid Infiltration Land Treatment Systems

A. Preapplication Treatment - Generally provide a lagoon with a design organic loading of 50 lbs/acre/day BOD_5 using a three (3) foot operating depth. Secondary treatment before land application is not required. The preapplication treatment level will be directly related to the intended irrigation use of the wastewater. As the opportunity for public access increases, pretreatment requirements should be more stringent. A short detention time aerated lagoon should be given due consideration when a lagoon does not exist. Also, aerators may be added to an existing lagoon which provides adequate storage to limit odor problems. The design engineer should remember that the purpose of the system is to provide storage and preapplication treatment.

B. Storage - If properly designed, none should be required. However, recommend the availability of about 10 days for possible mechanical failure should be adequate.

C. Preapplication Chlorination - If the method of application is designed and operated to minimize the production of aerosals, preapplication chlorination should not be required. This will be determined on a case-by-case basis depending on the application system proposed.

D. Hydraulic Loading Rate - 4.0 inches/week minimum application rate on a yearly average. The design should be made on the basis of a water balance and on-site soils investigations to support the capability of the selected site to accept the recommended loading for the deisgn period.

E. Distribution System - Typically this is a flooding-resting sequence utilizing ponds or trenches. However, high rate irrigation may be used in which case the systems would be much like that in the spray irrigation system.

F. Infiltration Basin Characteristics

1. Slope - Generally less than 2%.

2. Soil Permeability - Greater than 0.6 inches/hour.

3. Depth to Groundwater Table - Recommend minimum of 10 feet unless underdrains are provided.

G. Vegetative Cover - Optional and not usually required or recommended in flooding mode of operation but may be desirable in some situations to enhance and/or maintain infiltration/perculation capacity.

H. Drainage/Collection System - Rainfall runoff must be intercepted and routed around system. Failure to do so may transport silt and fines which would clog the infiltration system. Underdrains and a surface discharge should be provided at the site except when the hydrogeologic study shows a direct pathway to a surface water. The direct recharge of a potable water supply aquifer or a possible water supply aquifer is a special case and will require special investigations and clearances through and by the MAWPCC.

I. Post Chlorination - The renovated wastewater discharge should be acceptable from the standpoint of fecal coliform concentration and therefore would not require disinfection. Consideration should be given to specific limits that the system is being designed to meet and the proximity of the discharge site to human habitation.

J. Buffer Zones - A buffer zone shall be provided around the treatment site. The size of this border is dependent upon application method, proximity to dwellings, roads, land use, etc. Although the width of the buffer zone is negotiable, a value of 50 to 100 feet would seem to be adequate for most cases in which precautions have been taken to minimize aerosal drift from the application basin.

K. Public Access and Protection Systems - This has been covered in buffer zones and chlorination practices. Access to the site should be controlled through the use of fences and gates to restrict public access and to prevent livestock from entering the site. A 3 to 5 strand barb wire fence is recommended.

L. Monitoring

1. Groundwater - Contact MAWPCC for these requirements.

2. Discharge to Surface Stream - MAWPCC will issue an NPDES permit which will outline the frequency of sampling and the parameters to be monitored in both the influent and effluent on discharging systems. Should the system be designed for zero discharge to surface water, a no discharge State permit will be issued by the MAWPCC.

SELECTED REFERENCES

1. Process Design Manual for Land Treatment of Municipal Wastewater, EPA 625/1-77-008.

2. Applications of Sludges and Wastewaters on Agricultural Land: A Planning and Educational Guide, MCD-35, March 1978.

3. Nutrient Removal from Cannery Wastes by Spray Irrigation of Grassland: Law, Thomas and Myers, 16080, November 1969.

4. Highlights of Research on Overland Flow for Advanced Treatment of Wastewater: Charles R. Lee et al; Misc. Paper Y-76-6, November 1976.

5. Overland Flow Treatment of Raw Wastewater with Enhanced Phosphorus Removal; Thomas, Bledsoe and Jackson; EPA - 600/2-76-131, June 1976.

6. Wastewater Engineering - Treatment/Disposal/Reuse, Metcalf and Eddy, Inc.; 2nd ed., 1979.

7. Wastewater Treatment Plant Design, WPCF, Manual of Practice - MOP 8, 1977.

☆ GPO 1980—677-094/1122